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SUMMARIES OF SOLID WASTE RESEARCH AND TRAINING GRANTS - 1970

Louis W. Lefke, et al

Environmental Protection Agency
Rockville, Maryland

1971

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Summaries of Solid Waste Research and Training Grants—1970

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DISCRIMINATION PROHIBITED—Title VI of the Civil Rights Act of 1964 states: "No person in the United States shall, on the ground of race, color, or national origin, be excluded from participation in, be denied the benefits of, or be subject to discrimination under any program or activity receiving Federal financial assistance." Therefore, projects supported by grants or awards from the Solid Waste Management Office, like every program or activity of the U.S. Environmental Protection Agency, must be operated in compliance with this law.

FOREWORD

THIS PUBLICATION marks the third issuance of *Summaries of Solid Waste Research and Training Grants.* The purpose of this updated review is to inform interested readers of completed and active solid waste research projects and training programs. It is anticipated and hoped that this compilation will assist competent researchers in determining gaps in solid waste management knowledge and help to stimulate the conception of new approaches to or modifications of existing practices which will result in improved overall solid waste management for the nation.

The Bureau of Solid Waste Management, the predecessor of the Solid Waste Management Office (SWMO) was established under authority of the Solid Waste Disposal Act, Public Law 89-272. Prior to this Act, a modest solid waste research effort (EF series) was supported by the former Division of Environmental Engineering and Food Protection. The lack of and need for an extensive and concerted research effort was recognized by the Congress in passing the 1965 Solid Waste Disposal Act. The Act authorized initiation and acceleration of a national research and development program for new and improved methods of proper and economic solid waste management. Grant, contract, and in-house efforts are coordinated to meet the Act directives designed to conserve natural resources, to reduce the amount of wastes and unsalvageable materials, and to encourage the recovery and utilization of potential resources in solid wastes.

There is probably no single approach applicable to the wide array of solid wastes generated. Further, solid waste characteristics are continually changing through product innovations, industrial process modifications, and general population living habit evolution. Solid waste storage, collection, transport, reuse, upgrading, and disposal practices have not kept pace with these changes.

The objective of the SWMO is to develop efficient and economical solid waste management practices to meet national needs. Extramural research is supported in practically all phases of the problem, for example, generation, collection, transport, reuse, health, and disposal. Research efforts receive from one to six years support, with the majority being for three years. Research results are beginning to accrue and this issuance is indicative of this fact. A "Findings" writeup, which is included for the first time, describes the major results. (Mention of commercial products does not imply endorsement by the U.S. Government.) Additional detailed information can be obtained from the publications listed for each grant. To further inform the research community, the SWMO is planning to publish comprehensive final grant reports that contain new and worthwhile information.

The training grant program is an effort to develop personnel with advanced technical know-how and interest in solid waste. Graduate-level training is offered to qualified students in solid waste-oriented programs. It is also the intent of the training program to produce professional workers in the solid waste field who will be qualified to utilize the recommendations accruing from the research effort.

The research and training grants described in this publication have produced worthwhile results that are being implemented, and the ongoing and planned projects hold the promise of further aiding the Nation in coping with its solid waste problems. The SWMO's grant support program, integrated with its other efforts, provides a unified vehicle to solid waste problem solutions.

—RICHARD D. VAUGHAN,
Assistant Surgeon General
Acting Commissioner
Solid Waste Management Office.

Contents

PAGE

SECTION I: RESEARCH GRANTS 1

Composts and Composting

Composting Fruit and Vegetable Refuse (T) 3
Conservation of Resources in Municipal Waste (T) 4
Nitrogen Cycle Ecology of Solid Waste Composting (T) 5
Animal Waste Composting with Carbonaceous Material (A) 6
Cellulose Degradation in Composting (A) 8
Effects of Garbage Compost on Soil Processes (A) 8
Fate of Insecticides in Composted Agricultural Wastes (A) 11
Waste Composts as Chelating Agents in Plant Nutrition (A) 12

Conferences and Symposiums

Conference of Institute for Solid Wastes (T) 13
National Conference on Packaging Waste Management (T) 14
National Conference on Solid Waste Management (T) 15
National Conference on Solid Waste Research (T) 15
National Symposium on Animal Waste Management (T) 16
National Industrial Solid Waste Management Conference (A) 16

Containers

Design of a Water-Disposable Packaging Container (A) 17

Farm and Field Wastes

A Study of Farm Wastes (T) 18
Disposal of Dairy Cattle Wastes by Aerobic Digestion (T) 19
Engineering Properties of Farm Wastes (T) 21
Handling, Treatment, and Disposal of Animal Wastes (T) 23
Identification of Odors in Feedlot Operations (T) 24
Livestock Waste Management and Sanitation (T) 25
Microbiological Stabilization of Animal Wastes (T) 27
Poultry Manure Disposal by Plow Furrow Cover (T) 27
Sanitary Engineering Applied to Livestock Manures (T) 29
A Recirculating Waste System for Swine Units (A) 30
Effects of Processing Poultry Manure on Disease Agents (A) 31
Research on Animal Waste Pollution Control System (A) 34
Survival of Pathogens in Animal Manure Disposal (A) 35

Hospitals

Bacterial Contamination from Hospital Solid Wastes (T) 36
Incineration of Infectious and Radioactive Solid Waste (T) 38
Hospital Solid Waste Disposal in Community Facilities (A) 39
Study of Institutional Solid Wastes (A) 40

(T) Terminated }
(A) Active } as of March 31, 1970

PAGE

Incineration and Incinerators

A Study of Incinerator Residue (T) 41
Smokeless Incineration of Bulky Municipal Refuse (T) 42
Systems Analysis of Shipborne Municipal Incineration (T) 43
Combustion Products from the Incineration of Plastics (A) 45
Continuous-feed Incineration of Municipal Refuse (A) 46
Criteria for Design and Control of Incinerators (A) 47
Fireside Metal Wastage in Municipal Incinerators (A) 48
Incineration of Plastics Found in Municipal Refuse (A) 49

Insects and Insecticides

Fly and Economic Evaluation of Urban Garbage Systems (T) 50
Integrated Control of the Housefly (A) 51
Succession and Ecology of Diptera in Cattle Droppings (A) 52

Planning and Management

Dynamic Evaluation Procedure; Refuse-Handling System (T) 54
Mathematical Analysis of Solid Waste Collection (T) 55
Mathematical Simulation of Refuse Collection and Disposal Systems (T) 56
Optimal Policies for Solid Wastes Collection (T) 57
The Physical and Chemical Composition of Municipal Refuse (T) 58
Comprehensive Studies of Solid Waste Management (A) 60
Decision Making and Solid Waste Disposal (A) 63
Standard Test Procedures for Municipal Solid Wastes (A) 65

Phytotoxins

Biologic Consequences of Plant Residue Decomposition in Soil (A) 66

Pyrolysis

Pyrolysis of Municipal Refuse (T) 68
Pyrolysis of Solid Municipal Wastes (A) 69

Reclamation and Reuse

Citric Acid from Citrus Wastes by Fermentation (T) 70
Garbage and Wastes for Mushroom Production (T) 71
Partial Oxidation of Solid Organic Wastes (T) 72
Useful Disposal of Auto Bodies and Discarded Tires (T) 72
Biological Conversion on Animal Wastes to Nutrients (A) 73
Biological Methane Formation (A) 74
Chemical Transformation of Solid Wastes (A) 76
Converting Incinerator Residue to Useful Materials (A) 77
Degradation of Waste Paper to Protein (A) 78
Engineering Properties of Compacted Ash Fills (A) 80
High-Energy Gas from Refuse Using Fluidized Beds (A) 81
Kinetics of Porteous Refuse Hydrolysis Process (A) 82
Laser-Mediated Lignin Solid Waste Fermentation (A) 83
Noncombustive Disposal of Solid Agricultural Wastes (A) 84
Photosynthetic Reclamation of Agricultural Solid and Liquid Wastes (A) 85
Poultry Offal Silage as a Feed Ingredient (A) 87
Radiolytic Hydrolysis of Cellulose (A) 87
Reclamation of Energy from Organic Refuse (A) 88
Refuse Reclamation by Size Reduction and Separation (A) 89

PAGE
Single-Cell Proteins from Cellulosic Wastes (A) 90
Studies on Modifications of Industrial Wastes (A) 92
Thermophilic Aerobic Process for Waste Treatment (A) 93
Use of Domestic Waste Glass for Urban Paving 94
Using Wastes Formed in Vegetable and Cheese Production (A) 95
Utilization of Bark Waste (A) 96
Utilization of Broiler Litter as Animal Feed (A) 99
Utilization of Fibrous Wastes as Sources of Nutrients (A) 100
Wood Waste Reuse in Controlled-Release Pesticides (A) 102

Safety

Solid Waste Disposal and Bird Hazard to Aircraft (A) 102

Sanitary Landfill

Microbiology and Acid Production in Sanitary Landfills (T) 105
Sanitary Landfill Investigation (T) 106
Special Studies of a Sanitary Landfill (T) 107
Pollution of Subsurface Water by Sanitary Landfill (A) 109
Preventing Landfill Leachate Contamination of Waters (A) 111
Stabilizing Sanitary Landfills by Injection Grouting (A) 111
Thermophilic Metabolism in Solid Substrates 112

Sea Disposal

Marine Disposal of Fine-Grained Waste Solids (A) 113

Transport

Pipe Transport of Domestic Solid Waste (A) 114

SECTION II: RESEARCH GRANT PROJECTS BY STATE AND PRINCIPAL INVESTIGATOR 117

SECTION III: TRAINING GRANTS 121

SECTION IV: RESEARCH AND TRAINING GRANT PRINCIPAL INVESTIGATORS 131

SECTION I

RESEARCH GRANTS

Composting Fruit and Vegetable Refuse

Mr. Walter A. Mercer
National Canners Association
Western Research Laboratory
Berkeley, California 94710

Grant No. UI 00524–04
Funds Awarded: $102,346
Project Period: Apr. 1, 1963 to Mar. 31, 1968

Objectives: To develop a rapid, aesthetically acceptable, reliable, and economic method of disposing—through accelerated aerobic composting—of high-moisture solid refuse produced in harvesting and in the processing of fruits and vegetables.

Approach: Pilot studies were conducted using aeration bins in which mixtures of fruit- and vegetable-canning wastes were composted with dry, moisture-absorbing materials such as redwood bark, straw, sawdust, rice hulls, coffee grounds, and final compost from the process. The effects of repeated additions of fresh waste with intermittent or continuous forced aeration were also investigated.

Using information obtained by these pilot bin studies, and parallel to them, large-scale windrow composting studies were made. The compost material was turned and mixed on a flexible schedule.

Findings: Ground fruit waste required a higher proportion of absorbent, but under these conditions the time required for the completion of a compost cycle was reduced by 50 percent. Lags in the development of desirable microflora and temperature were overcome by the addition of lime, if caused by a low pH of the initial compost mixture.

The addition of nutrients, such as a nitrogen source, stimulated microbial growth and accelerated the compost cycle. Composted municipal refuse and rice hulls were two absorbent materials that performed satisfactorily without modification. Shredded redwood bark failed to absorb moisture adequately and appeared to inhibit microbial growth because of its high tannin content. Evaporation during composting of fruit waste (85 percent moisture) and microbial conversion of sugar and acids to carbon dioxide and water resulted in substantially reduced weight and volume of the finished compost. Air-dried compost could be recycled as the absorbent for fresh waste. The weight and volume of the finished compost increased only slightly when it was recycled several times. Offensive odors did not develop during the composting process nor was fly breeding observed.

Use of the first open windrows, having varied heights and volumes of rice hulls, indicated that the height of the mass was important to efficient composting. Waste could be frequently added without altering microbial degradation. Thus, open windrows could not provide the height required for efficient composting, and it was necessary to contain the compost mixture between permanent walls. Forced aeration—injecting air up through the compost mass—was superior to strictly mechanical means of providing aerobic conditions. Without forced aeration, anaerobic pockets developed within the windrow. Thermophilic temperatures were sustained throughout an operating season by applying waste every day. Wastes were added and the compost turned at 12-hr intervals; this increased the quantity stabilized within a given time. An automated means of turning the windrow mass was developed. A quarry rock and gravel removal machine was modified to mix, turn, and aerate the windrows.

From a technologic standpoint, the compost process is a feasible method of stabilizing high-moisture solid wastes such as those resulting from fruit and vegetable processing. Continuous thermophilic degradation of organic waste, sustained over an operating season, provides for the most efficient stabilization of wastes with a given volume of absorbent material. Equipment required to carry out an automated composted process has been developed and evaluated. Precise cost figures

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for the operation of full-scale units are not yet available.

PUBLICATIONS

MERCER, W. A., W. W. ROSE, L. W. RIEGER, and J. E. CHAPMAN. Better washing of asparagus to improve quality and prevent spoilage. Research Laboratory Report No. 60–W–46. Berkeley. National Canners Association Research Laboratories, Western Branch, Feb. 17, 1960.

ROSE, W. W., J. E. CHAPMAN, and W. A. MERCER. Composting fruit waste solids. *In* Proceedings of the Eleventh Pacific Northwest Industrial Waste Conference—1963, Corvallis, May 9–10, 1963. Oregon State University. (Engineering Experiment Station Circular No. 29.)

MERCER, W. A. Industrial solid wastes; the problems of the food industry. *In* Proceedings; National Conference on Solid Waste Research, Chicago, Dec. 1963, University of Chicago Center for Continuing Education. Special Report No. 29. American Public Works Association, 1964. p. 51.

ROSE, W. W., and W. A. MERCER. Treatment and disposal of potato waste. *In* Proceedings; International Symposium; Utilization and disposal of potato wastes, Fredericton, New Brunswick, Canada, May 24–27, 1965 New Brunswick Research and Productivity Council, 1966.

ROSE, W. W., J. E. CHAPMAN, S. ROSEID, A. KATSUYAMA, V. PORTER, and W. A. MERCER. Composting fruit and vegetable refuse. *Compost Science* 6(2):13–25, Summer 1965.

Conservation of Resources in Municipal Waste

Dr. Clarence E. Scarsbrook
Department of Agronomy and Soils
Auburn University
Auburn, Alabama 36830

Grant No. EC 00243–03
Funds Awarded: $213,287
Project Period: Apr. 1, 1967 to Mar. 31, 1970

OBJECTIVES: To evaluate the use of composted refuse for agricultural applications ranging from its use as a source of nitrogen for established grasses to its serving as an organic additive for production of greenhouse container and cut crops. Compost was also evaluated for its use for woody plants, highway planting, and as a cover for revegetating areas denuded of topsoil. Additional subjects were the comparison between composted refuse and peat, sawdust, and other materials as sources of organic matter in establishing grasses, and also the biological properties of compost when added to soil. Composted garbage was evaluated for its effect on the amelioration of the toxicity of certain herbicides.

APPROACH: Processed municipal solid waste, sawdust, and peat were compared in experiments for use on highway median strips, highway backslopes and fills, strip mines, and borrow areas. The effects of these materials during the establishment of different types of grasses were determined. The effects of including processed garbage in a hydroseeding operation and of including garbage and activated sludge with peat as a mulching agent were evaluated. Experiments compared ammonium nitrate applied at rates of 80 and 400 lb of nitrogen per acre per year with processed garbage.

Laboratory work involved incubating soil samples with compost applied as a mulch and as incorporated into the soil and determining the release of CO_2, N, P, and S. The C:N ratio as well as the development of cation exchange capacity were established.

FINDINGS: Garbage compost added at the rate of 100 tons per acre to soils ranging in texture from loamy sands to clays ameliorated the toxicity to crops of certain herbicides but had no effect on others. Fluometuron and trifluralin (each at 30 lb/acre) were toxic to cotton without compost additions; however, with compost there was considerably less toxicity of the herbicides on cotton. Compost did not reduce the toxicity of bromacil (50 lb/acre), picloram (30 lb/acre), or simazine (30 lb/acre).

Garbage compost, when first applied to soils, was often toxic to seedlings, but there was little injury when the soil was reseeded 4 to 6 weeks after application of compost. The two garbage composts used as received from the supplier both require large amounts of N and P for plant growth; however, as the compost ages it becomes more nearly satisfactory as a medium for plant growth.

The composts compare favorably with hay and pine straw as a mulch for erosion control.

The garbage composts used do not appear promising as a part of the growth medium for ornamentals but may be satisfactory as mulches.

PUBLICATIONS

ORR, H. P., K. C. SANDERSON, and W. C. MARTIN, JR. Comparison of processed garbage, sawdust, and pine straw in mulching garden chrysanthemums 1967. Research Results for Nurserymen, Auburn University Agricultural Experiment Station, Horticultural Series No. 10:6. Aug. 1968. (Abstract.)

SANDERSON, K. C., H. P. ORR, and W. C. MARTIN, JR. Comparison of processed garbage, sawdust and pine straw in mulching petunias 1967. Research Results for Nurserymen, Auburn University Agricultural Experiment Station, Horticultural Series No. 10:6–7. Aug. 1968. (Abstract.)

SANDERSON, K. C., R. SELF, H. P. ORR, and W. C. MARTIN, JR. Utilization of processed garbage-sludge as a media additive in the production of woody plants in containers. Research Results for Nurserymen, Auburn University Agricultural Experiment Station, Horticultural Series No. 10:5–6, Aug. 1968. (Abstract.)

SANDERSON, K. C., H. P. ORR, and W. C. MARTIN, JR. Utilization of processed garbage in the production of selected ornamentals. Proceedings; Association of Southern Agricultural Workers, 65:160–161. 1968. (Abstract.)

DICKENS, R., D. G. STURKIE, J. D. MILLER, and J. L. MORGAN. Utilization of composted garbage for turf establishment. Proceedings; Association of Southern Agricultural Workers, 66:87–88, 1969. (Abstract.)

SCARSBROOK, C. E. Fertility requirements of municipal garbage compost for plant growth. Proceedings; Association of Southern Agricultural Workers, 66:96, 1969. (Abstract.)

HILTBOLD, A. E., and G. A. BUCHANAN. Use of garbage compost in reduction of toxic residues of herbicides in soil. Proceedings; Association of Southern Agricultural Workers, 66:102, 1969. (Abstract.)

Nitrogen Cycle Ecology of Solid Waste Composting

Dr. David T. Knuth
Institute of Environmental Studies
Gainesville, Florida 32601

Grant No. UI–00548–02
Funds Awarded: $47,540
Project Period: June 1, 1966 to Sept. 30, 1968

OBJECTIVES: To investigate the fate, recycling, and use of nitrogen compounds in the composting of solid waste. To investigate the kinds of nitrogen bacteria present, and to correlate nitrogen products present with microbial activity. To predict and evaluate the effect of environmental changes on composting efficiency and on conditions necessary for maximum nitrogen utilization.

APPROACH: Composting was done in the laboratory to obtain good experimental control and reproducibility by using a specially constructed fermenter to simulate the windrow method used in industrial operations. The fermenter was used to obtain results directly applicable to windrow operations run on the batch basis, and, in some cases, results were applicable to continuous thermophilic composting systems. The mesophilic, thermophilic, ambient, and curing stages of composting were studied.

The nitrogen economy of each phase was examined by using wet chemical, isotopic, mass spectrographic, and gas chromatographic methods. Microbial nitrogen activity in each stage was determined by quantitating the nitrifying, denitrifying, ammonifying, and nitrate-reducing groups. The rate of the composting process was measured in terms of CO_2 production in the total system, whereas the BOD approach was used to measure the degree of stabilization.

FINDINGS: Some of the soil-nitrogen-cycle transformations were detected in the mesophilic stage of composting. Inorganic nitrogen compounds sometimes accumulated in concentrations representing nearly 20 percent of the total nitrogen present. Organic nitrogenous compounds were hydrolyzed and ammonified, even though other organic compounds in the waste were not noticeably decomposed. The results suggest that losses of nitrogen that may follow ammonification in subsequent stages of composting could be prevented by equalizing the rate of ammonification and the rate of immobilization by the composting microflora. No nitrogen was lost either as gas or as nonexchangeable nitrogenous compounds.

Microbial activity reached its maximum at about 12 hours, declined rapidly to about one-half maximum, and remained at almost that level for up to 3 or 4 weeks. Microbial activity did not correlate with the BOD reduction rate, which declined rapidly after 8 days.

Nitrogen transformations play a critical role in the conservation and utilization of nitrogen in the composting process. It is becoming increasingly evident that ammonification and nitrification must be controlled or regulated to ensure efficient utilization of nutrient nitrogen. This may be a critical requirement in substantially improving composting rates and quality. Methods used to control nitrogen conversions in the soil might also be applicable in composting.

Animal Waste Composting with Carbonaceous Material

Dr. William S. Galler
Department of Soil Science
North Carolina State University
Raleigh, North Carolina 27607

Grant No. EC 00270-02
Funds Awarded: $54,084
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To develop a process for composting a combination of chicken manure as a source of nitrogen and sawdust initially as a source of carbon to produce a valuable soil amendment.

APPROACH: Poultry manure and sawdust are used as model organic waste materials representing both high and low nitrogen-containing wastes. The carbon-to-nitrogen ratios of these materials are determined. Then the materials are mixed to produce an initial carbon-to-nitrogen ratio of 25:1. The aerobic composting characteristics of this composite sample are studied under controlled conditions of temperature to determine the optimum temperature for rapid composting. The C:N ratio is then varied to determine the optimum mixture of manure to sawdust. The moisture content of the mixture is then varied to determine an optimum condition. The experiments are conducted in a 45-cu-ft, horizontal, rotating drum with provisions for controlling airflow, adding raw material, and removing finished compost.

The microflora found to be adapted to these conditions are identified and studied in terms of their physiologic and nutritional requirements for ensuring maximum composting rates while an end product that is most desirable as a soil amendment is being produced.

The final stages of this project involve determining bulk handling characteristics and field performance of several possible end products. The compost is being applied at several rates to various soils, and the response of high value crops is being determined.

FINDINGS: *Batch composting.* The mixture of sawdust and poultry manure, blended in carbon-to-nitrogen ratios (C:N) of 25:1 to 40:1, was analyzed chemically and found to be nutritionally balanced for microbial growth. Mixtures of sawdust and manure ranging from C:N of 25:1 to 40:1 were then composted batchwise in the drum composter with varying moisture contents.

Maximum microbial activity was observed at moisture levels of 55 to 60 percent. At more than 65 percent moisture, the mixture formed balls that hindered the aerobic activity. The moisture content did not vary by more than 1.2 percent during a given run.

The oxygen uptake rate for the C:N mixture of 25:1 was almost 33 percent greater than that of the 40:1 mixture (4.19 mg of oxygen per g of volatile solids versus 3.3 mg of oxygen per g of volatile solids). Temperatures above 60 C were also sustained almost three times longer for the C:N mixture of 25:1. Although at least 80 percent or more of the carbon was supplied by the sawdust, less than 25 percent of the reduction in volatile solids could be attributed to the sawdust. Thus, the available carbon during the composting period was supplied by the manure.

The nitrogen loss during the high-rate composting period averaged only 3.29 percent, much less than anticipated.

The maximum time used in studying an individual batch was about 5 to 7 days in the composter. Sixteen batch studies were performed.

After being removed from the composter, the holocellulose decreased in content from 66 to 54 percent and became fairly stable after 4 weeks. The cation exchange capacity increased during this period to 69 meq/100 g.

The final compost has a blackish-white color and an odor similar to that of fresh humus soil. Moreover, the cation exchange capacity is at a level characteristic of a desirable soil conditioner.

Continuous composter operation. During the period of continuous operation, poultry manure was not available and swine manure was substituted. A batch study showed that swine manure was satisfactory, although the mixture required a week to become thermophilic as opposed to 1 to 2 days for the poultry manure.

A second batch was started. After the composting mixture had been in the thermophilic region for 24 hours, one-third of the mixture was replaced by a fresh manure and sawdust mixture. The feeding process was continued for 2 weeks, after which the process was allowed to halt. After each feeding, the temperature dropped from above 60 C to 45 to 50 C. The 60 C plus temperatures were again reached after about 6 to 8 hours. The product removed from the composter appears similar to the poultry manure-sawdust end product. Chemical analyses have not yet been completed.

Plant growth studies. Initial studies were made by spreading the compost as a mulch on patches of grass at the composter site. The area was divided into 1.35-sq-m units and treated with 0, 3, 6, or 12 qt of compost. No difference was found among the areas treated with compost; however, the grass clipped from the treated areas had a dry-weight increase of 22 percent and a nitrogen content 30 percent greater than the untreated areas.

Greenhouse studies using the compost mixed with otherwise untreated soil are being conducted with tomatoes, millet, wheat, and green beans. Ten applications of compost are being used ranging from 0 to 100 percent compost. When compared with the 0 percent treatment, the 10 percent treatment was found better for the tomatoes, millet, and wheat. The beans showed the best growth at the 1 percent level. The increase in dry weight was found to be 400 percent for the tomatoes, 354 percent for the millet, 238 percent for the wheat, and 153 percent for the green beans. The tomato yield was also greater at the 10 percent level. The bean seed yield was greatest at the 1 percent level as was the nodule count on the bean roots.

Tissue studies are in progress. These studies indicate that the compost is a valuable soil conditioner.

Cellulose Degradation in Composting

Dr. John S. Jeris
Department of Civil Engineering
Manhattan College
Bronx, New York 10471

Grant No. EC 00161–04
Funds Awarded: $125,872
Project Period: Aug. 1, 1966 to July 31, 1970

OBJECTIVES: To investigate and determine the environmental conditions required for accelerated cellulose and refuse degradation by microorganisms by use of composting procedures. To translate the results into engineering information so that urban refuse may be treated more economically by use of the compost process.

APPROACH: Laboratory studies used a battery of three continuously fed composters. These bench-scale studies were designed to determine the maximum rate of solid waste stabilization under appropriate physical and chemical environmental conditions. The study materials included (1) municipal refuse; (2) a synthetic refuse composed of paper, vegetables, and meat scraps; and (3) paper with nutrient additives. Cellulose and degradation products were assayed so that a measure of the system's efficiency and the metabolic mechanisms could be obtained.

In conjunction with the bench-scale composters, Warburg and shake flask apparatuses were used to scan stabilization rates of the solid waste materials over wide ranges of various environmental parameters.

FINDINGS: The maximum rate of municipal refuse composting obtained, as measured by oxygen consumption, was approximately 50 percent greater than the highest rate reported in the literature. At this high rate the significant parameters included (1) a pH of 8 to 8.5, (2) a temperature of 58 to 62 C, (3) a nitrogen-to-carbon ratio of 1 to 30, and (4) a moisture content of 65 to 75 percent with a minimum free-air space of 30 percent.

The rate of degradation obtained with mixed refuse containing 60 to 70 percent paper is about 10 times greater than with a pure paper solid waste. In general, an increase of paper content means a decrease in stabilization rate owing to the nonbiodegradeable nature of paper.

The stabilization rate decreases significantly during composting at a material turnover rate greater than 4 days. Higher rates of biological stabilization are maintained by recycling composted material as a seed with fresh refuse. A recycle rate of 50 percent has given maximum results.

Effects of Garbage Compost on Soil Processes

Dr. Charles C. Hortenstine
Department of Soils
University of Florida
Gainesvile, Florida 32601

Grant No. EC 00250–04
Funds Awarded: $74,161
Project Period: Dec. 1, 1966 to Nov. 30, 1971

OBJECTIVES: To evaluate the effects on structure, fertility, and biological activity of adding municipal refuse compost to the soil. To evaluate the use of compost as a plant nutrient and to determine toxic or beneficial effects of compost on soil when it is applied over short and long time periods. To evaluate the water pollution potential of compost.

Approach: Laboratory, greenhouse, and field studies are being conducted concurrently. Laboratory studies have been undertaken to isolate organisms effective in decomposing organic refuse. The conditions of temperature and moisture content of the compost that produce maximum composting rates are being determined. The compost is being analyzed for plant nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and copper as well as organic matter content. Laboratory studies are also determining the water-holding capacity, density, cation exchange capacity, and pH of the compost. Leaching studies are being conducted to determine the ground water contamination potential of compost.

Greenhouse studies are being done to determine the nutrient availability of compost as compared with sewage sludge, mineral fertilizers, and animal manures. The potential of compost as a potting medium for ornamental plants is being thoroughly investigated. Soil characteristics of compost and compost-soil mixtures are being evaluated to determine characteristics such as water-holding capacity, pH, aeration, and drainage properties.

Field studies are being conducted throughout Florida on major soil types to compare compost with other fertilizers as a plant nutrient. Field studies are also determining the maximum amount of compost that can be mixed with various soil types without producing conditions toxic to various plants.

Findings: Composting municipal waste under controlled conditions is advantageous from the following viewpoints: (1) Salvaging of paper and metals is feasible. (2) There is no air or water pollution hazard. (3) There is no health hazard due to fly or rodent populations. (4) The composted material may be used as a soil-improving amendment. Municipal refuse starts, however, as a waste product and remains a waste product throughout the composting operation. In other words, the philosophy that a salable material is produced from composting municipal refuse is not a valid premise.

Laboratory. Composted refuse is variable in physical makeup and chemical constituents. This variability is present between day-to-day and season-to-season collections. A typical sample of composted refuse from the Gainesville plant contained 0.57 percent nitrogen, 0.26 percent phosphorus, 0.22 percent potassium, 33 ppm boron, 24 ppm manganese, 606 ppm zinc, 1.88 percent calcium and 0.12 percent magnesium. This sample was about 45 percent water on a wet-weight basis (79 percent on dry-weight basis), 38 percent ash, 2.50 percent total soluble salts, and had a pH of 6.85.

In a laboratory experiment where compost was mixed with Arredondo fine sand, there was a large increase in fungal populations. Bacterial populations also increased after 4 days in soil containing 10 percent compost, but these populations decreased again after a few days. In carbon dioxide evolution, compost was intermediate between chicken manure (which was high) and cow manure (which was low). Almost no nitrification occurred where compost was added to the soil. This was probably due to rapid immobilization of nitrogen by the soil microflora. In applying compost to the soil, this characteristic must be compensated for either by applying additional nitrogen or by delaying planting until the soil microorganisms release nitrogen. This delay may be for a period of 3 to 4 weeks or as long as 6 months, depending on the amounts of compost applied and climatic conditions.

Of particular interest was the effect of compost on nematode survival and motility. Where sting nematodes, *Belonolaimus longicaudatus*, were placed in compost extract, motility ceased after 2.8 hours' exposure. This was attributed to the organic fraction, since nematodes placed in extract from which the organic fraction was removed were unaffected.

In another experiment, survival of African Giant earthworms in Arredondo fine sand was increased by additions of compost. As little as 2.5 percent compost was effective; however, compost was not as good a medium for earthworms as peat.

Greenhouse. In several experiments where compost was added to soil, plant growth was enhanced. Generally, however, there was an initial tieup of nitrogen by soil microorganisms that was detrimental to the first crop grown. Subsequent crops showed increased yields as compared with controls only where large amounts (128 metric tons or more per hectare) of compost were applied. In this respect, compost could not compete with mineral fertilizer unless the compost was free.

Where compost was applied to soil at rates of 128 or more tons/hectare, soil phosphorus, potassium, calcium, magnesium, pH, and total soluble salts were increased greatly. Soil phosphorus was also increased at much lower rates of compost (2 tons/hectare). Cation exchange capacity and water-holding capacity of the soil were increased greatly where 128 or more tons of compost were applied. Soil aeration and granulation were also improved. In one experiment where 2,048 tons of compost were applied per hectare, aeration was improved to such an extent that manganese was rendered unavailable for plant use. (Plant roots absorb manganese as the Mn^{+2} state, and oxidation changes it to the Mn^{+4} state.) Moreover, at such high rates total soluble salts became a problem, as was manifested by phytotoxicity in one crop of radishes.

Germination. The effect of compost on seed germination is of major concern. In one experiment, compost was extracted in 500 ml of water, and the extract was used as a moistening agent for seed germination. Where 80 g of compost were extracted, radish seed germination was reduced to 56 percent. Extract from 160 g of compost reduced radish seed germination to 16 percent and turnip seed germination to 40 percent. Extract from 320 g of compost reduced germination of all seeds tested—radish to zero, turnip to zero, oat to 41 percent, and pearl millet to 45 percent. Seedlings that made any growth in the 320-g extract showed evidence of phytotoxicity and were much smaller than seedlings in the other extracts. The phytotoxic effects were thought to be the result of total soluble salts since conductivity was increased greatly as the amounts of compost extracted increased—from 1.97 millimhos per cm in 10 g to 26.60 millimhos per cm in 320 g (more than 8 millimhos per cm is considered a strongly saline solution). This soluble salt effect is another indication that there should be a time lapse between applications of compost to seeding, so that leaching of soluble salts below the root zone can be allowed for.

Field experiments. A study was conducted on Leon fine sand to determine the effects of compost applications on nematode populations. Where 8, 16, and 32 tons of compost per hectare were applied, spiral nematodes, *Helicotylenchus* spp., were reduced in number as compared with lower compost rates or mineral fertilizer. Ring nematodes, *Circonemoides* spp., were also lower in plots where 32 tons of compost per hectare were applied. *Dorylaims* and *Rhafditids* were significantly higher in soil from the 32-ton-per-hectare plots.

An experiment initiated 2 years ago at International Minerals Corporation, Bartow, Florida, shows promise of yielding invaluable information. This experiment was designed to determine the effects of adding compost to the sand fraction left as a waste product after the flotation process, which removes phosphorus from the matrix. Two rates (35 and 70 tons of compost/hectare) were applied to plots on this sand during April of 1968 and 1969. Mineral fertilizer (10-10-10) was also applied to plots with no compost and to plots where the compost was applied. Two crops (sorghum and oats) were grown each year.

Oats were not harvested in 1969. Oats are growing, however, in the plots receiving compost only where there were no surviving plants in 1968. There was undoubtedly a residual effect from compost applied in 1968. This was also shown by much larger sorghum seedhead yields (272 g overall average in 1968 as compared with 669 g in 1969). In addition to yield benefits, there was a small but highly significant increase in cation exchange capacity and water-holding capacity of the sand as the result of compost application.

Summary. Research to date has shown that composted municipal refuse applied to soil is beneficial both to plants and the soil. In order, however, to reap any benefit from compost, relatively large amounts must be applied to the soil. In other words, the soil must be considered as a solid waste disposal sink. Any detrimental effects to the soil or plant life will soon dissipate under favorable climatic conditions.

Laboratory research indicated that compost applied to the soil reduced nitrification to almost zero. This may have great implications in the field in conjunction with animal waste management. Of major concern where animal wastes are applied to the soil is movemet of nitrates into potable water supplies. An experiment was recently initiated in which various levels of compost were applied to soil in small lysimeters. The objective is to study the effects on nitrification when cow manure is applied to the same soil. If compost does reduce or delay the movement of NO_3 into ground water supplies, this will certainly be a worthwhile finding.

PUBLICATIONS

ROTHWELL, D. F., and C. C. HORTENSTINE. Composted municipal refuse: Its effects on carbon dioxide, nitrate, fungi, and bacteria in Arredondo fine sand. *Agronomy Journal*, 61 (6):837–840, Nov.–Dec. 1969.

HORTENSTINE, C. C., and D. F. ROTHWELL. Garbage compost as a source of plant nutrients for oats and radishes. *Compost Science*, 9(2):23–25, Summer, 1968.

HORTENSTINE, C. C., and D. F. ROTHWELL. Utilizing municipal refuse in reclaiming phosphate mining spoil areas. Presented at Annual Meeting, Association of Southern Agricultural Workers, Memphis, Feb. 2–4, 1970.

ROTHWELL, D. F., and C. C. HORTENSTINE. Effect of composted municipal refuse and other organic wastes on microbial activity. Presented at Annual Meeting, Association of Southern Agricultural Workers, Memphis, Feb. 2–4, 1970.

Fate of Insecticides in Composted Agricultural Waste

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Grant No. EC 00264–04
Funds Awarded: $74,356
Project Period: May 1, 1966 to Aug, 31, 1970

OBJECTIVES: To determine the fate of insecticides in composting agricultural wastes by isolation, separation, and identification of residues of the original insecticide and its major transformation products. Representative insecticides of the three major classes, i.e., chlorinated hydrocarbon, organophosphate, and carbamate, were incorporated singly and as mixtures in tomato, peach, potato, and fresh produce market wastes before composting. The effect of both continuous and batch-type composting operations on the breakdown of insecticides was evaluated by using pure cultures of microorganisms predominating in the aerobic compost process.

APPROACH: Wooden bins capable of holding 1 cu yd of compost material were filled with the proper ratio of organic waste and absorbent material. The waste material was analyzed for field-applied insecticides, and then purified insecticides were added in the following concentrations: 7 to 20 ppm DDT, 1 to 5 ppm dieldrin, 2 to 10 ppm parathion, 1 to 5 ppm Diazinon®, 10 to 25 ppm Sevin®, and 5 to 15 ppm zineb. Regularly scheduled samples were taken during the composting and curing periods and, after extraction and purification, were analyzed by gas, paper, or thin-layer chromatography with the addition of infrared spectroscopy on unknown products.

In the composting system whereby specific insecticides are markedly degraded, the responsible organism was isolated and cultured. These pure culture studies provided samples from which degradation products of the insecticides could be readily isolated and identified. The pure culture studies also established the ability of selected microorganisms to attack the test insecticides under the prevailing pH, temperature, and moisture conditions of the compost mixture.

FINDINGS: The batch-type and continuous thermophilic compost procedures effectively reduced the levels of organophosphate- and carbamate-type insecticides. Degradation was faster in the thermophilic process. For example, to reduce the Diazinon concentration by 50 percent it took 10 days at thermophilic temperatures and 28 days in the batch-type system.

Known degradation products for Diazinon included oxodiazinon and sulphotepp. Breakdown products for parathion included amino parathion, p-aminophenol, and p-nitro phenol.

Results for the chlorinated hydrocarbons support the finding by others in regard to their long persistence. There was a gradual loss of pp DDT during composting at 110 to 140 F. At lower temperatures there was no loss, and this indicated that the observed decline in DDT was probably due to volatilization. Dieldrin was less persistent than DDT and the batch-type process was more effective than the thermophilic process. After 75 days of composting, the dieldrin concentration approached a nondetectable level in the batch-type process. For the same time interval the thermophilic process showed a reduction of 50 percent. Known breakdown products for DDT and dieldrin were not detected in the compost samples.

The two carbamates, carbaryl and zineb, disappeared very rapidly from both compost systems. The persistence of carbaryl was found to be highly dependent upon the pH. Alkaline pH's accelerated its hydrolysis. Laboratory studies with buffered insecticide solutions confirmed the effect of pH on carbaryl. At a pH of 8.0 or 9.0 the initial concentration of 60 ppm was reduced to a nondetectable level within 22 days. At pH 7.0 approximately 80 percent of the carbaryl was lost within 50 days. At pH 4.0 very little change had occurred in the concentration after 50 days of incubation.

Bacteria were the most predominant type of microorganisms with both methods. Actinomycetes were next, followed by fungi. The type of insecticide used apparently had no influence on the microflora that developed within the compost mass.

The total numbers of bacteria were about equal with both processes. The numbers of actinomycetes and fungi were higher with the batch-type procedure. There was a slight decline in the total numbers of each microflora with time of composting.

Incubation of compost extract in a mineral salts medium and in insecticide resulted in the isolation of some microorganisms. By this procedure six isolates have been obtained that grow in the presence of Diazinon or parathion. One isolate has been obtained from the dieldrin extracts. Further work should provide additional isolates for study in determining a pattern of insecticide utilization and degradation.

PUBLICATIONS

ROSE, W. W., W. A. MERCER, A. M. KATSUYAMA, S. ROSEID, V. Y. PORTER, J. T. YAMADA, J. A. HESP, and J. MARANO. Fate of insecticides in composted agricultural wastes. Unpublished data. [1967.]

FARROW, R. P., E. R. ELKINS, W. W. ROSE, F. C. LAMB, J. W. RALLS, and W. A. MERCER. Canning operations that reduce insecticide levels in prepared foods and in solid food wastes. *Residue Reviews*, 29:73–87, 1969.

Waste Composts as Chelating Agents in Plant Nutrition

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Grant No. EC 00273–02
Funds Awarded: $36,945
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To test the hypothesis that composts and related organic materials either contain or can produce organic compounds capable of chelating insoluble nutrient elements in the soil. The addition of such composts would be beneficial in those soils that show specific micronutrient deficiencies.

Approach: Solid waste compost and other related organic materials are added to soils known to be deficient in specific nutrients. Plants are grown on these soils under carefully controlled greenhouse or growth chamber conditions. Growth response to the added compost is measured. Initially, a soil showing zinc deficiency and another showing iron deficiency were used in these studies. An increase in plant growth, the nutrient uptake by the plant and the nutrient composition of the added organic material being known, would indicate that the hypothesized metal chelation may be a contributing factor. Period of incubation, rate of application, and other variables are being investigated in order to consider a variety of experimental parameters.

The solubilization of micronutrient cations in waste compost by the organic materials from the decomposing compost is being studied. Soluble metal complexes or chelates in soil extracts are identified by using dialysis, chromatography, and infrared absorption techniques. Extracted organic matter from soil-compost mixtures is being studied for stability constants of Zn, Fe, Cu, and Mn complexes.

Findings: A series of greenhouse studies showed that sewage sludge and garbage compost are somewhat beneficial for correcting Zn and Fe deficiencies in high-pH soils. Ashing the organic wastes greatly reduced their effectiveness as Zn and Fe fertilizers. The organic-matter fraction was beneficial in keeping those relatively insoluble nutrients soluble and available for plants.

Sewage sludge initially contained a high level of DTPA-extractable (available) Fe. During incubation with soil, only a small but significant fraction remained available. Increased availability persisted for at least three cropping cycles. On a dry-weight basis sewage sludge was more effective than garbage compost in correcting these micronutrient deficiencies. N, P, K, and S were adequately supplied so that growth response resulted primarily from added Zn or Fe.

Water-soluble extracts of sewage sludge, garbage composts, and soils to which these wastes were incubated were examined to identify possible chelating agents responsible for the solubilization of metal ions in soil. Separations of the water-soluble extracts on Sephadex G-25 columns gave five molecular-weight fractions. When ^{59}Fe was added to the extracts, it was retained by the higher molecular-weight fraction. Further separation and identification of the functional groups responsible for metal chelation are in progress, by use of chromatographic and infrared absorption techniques.

The study indicates that solid waste products such as garbage composts and sewage sludges are useful micronutrient fertilizers on soils deficient in these nutrients. Identification of soluble metal chelates arising from decomposing organic residues is contributing fundamental information on the beneficial role of organic matter in restoring soil fertility.

Conference of Institute for Solid Wastes

Mr. Robert D. Bugher
Executive Director
American Public Works Association
Chicago, Illinois 60600

Grant No. SW 00023-01
Funds Awarded: $10,000
Project Period: June 1, 1966 to Dec. 31, 1966

These funds supported, in part, the first annual meeting of the Institute for Solid Wastes (ISW) of the American Public Works Association (APWA), held in Chicago, Illinois, Sept. 10 to 15, 1966. The Institute was formed Aug. 29, 1965, within the structure of the APWA. The meeting was held in conjunction with the 1966 Public Works Congress and Equipment Show.

The funds helped to defray expenses incurred by specially invited representatives of the International Association of Public Cleansing (INTAPUC) in establishing an international relationship within the national framework. The participation of experts in the field of solid wastes from other countries enhanced the conference, which focused on solid waste management research.

A summary of the Joint Meeting of the Executive Councils of INTAPUC and ISW was published in the 1966 Proceedings of the APWA-ISW. The meeting prepared the groundwork for the merger of INTAPUC and the International Research Group for Refuse Disposal. The two groups merged into the International Solid Wastes Association (ISWA) effective Jan. 1, 1970. ISWA has as its purpose the development of international relations and the exchange of information on solid wastes and public cleansing The APWA-ISW is the official national representative for the United States and Canada in the ISWA. Robert D. Bugher, Secretary-Treasurer of the APWA-ISW and Executive Director of the APWA, is currently Vice President of the ISWA.

PUBLICATIONS

Proceedings; First Annual Meeting of the Institute for Solid Wastes, Chicago, Sept. 13-15, 1966. American Public Works Association. 78 p

National Conference on Packaging Waste Management

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Grant No. EC 00324-01
Funds Awarded: $21,856
Project Period: Feb. 1, 1969 to Jan. 31, 1970

OBJECTIVES: To ascertain the changing nature and dimensions of the packaging wastes problem and to explore avenues for solutions to this problem, with due regard for scientific and technologic aspects, economic and sociologic factors, legal aspects, and public information.

APPROACH: A conference on packaging and waste management was held September 22 to 24, 1969, at the Sheraton-Palace Hotel, San Francisco, California. Its purpose was to bring together university, government, and industry personnel to examine the magnitude, complexity, and growth rate of packaging waste material, and the technical and economic factors related to its management. A complete proceedings of the conference has been published.

PUBLICATION

First National Conference on Packaging Wastes; proceedings, [San Francisco,] September 22-24, 1969. Washington, U.S. Government Printing Office, 1971. 242 p. (In press.)

National Conference on Solid Waste Management

Dr. Samuel A. Hart
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Grant No. SW 00037–01
Funds Awarded: $24,069
Project Period: July 1, 1965 to Dec. 31, 1966

These funds supported, in part, a National Conference on Solid Waste Management held on Apr. 4 and 5, 1966, at Davis, California, that explored operations research and systems analysis as possible tools in improving the approach to the involved problems of solid waste management in metropolitan areas.

Approximately 350 persons attended the meeting. Representatives from the U.S. Public Health Service, universities, industry, governmental agencies, and private institutions presented papers that were published.

PUBLICATIONS

Solid Wastes Management; Proceedings; National Conference, Davis Campus, April 4–5, 1966, University of California. 214 p.

National Conference on Solid Waste Research

Dr. Ross E. McKinney
Department of Civil Engineering
University of Kansas
Lawrence, Kansas 66044

Grant No. EF 00549–01
Funds Awarded: $18,478
Project Period: July 1, 1963 to June 30, 1964

OBJECTIVES: These funds supported, in part, a National Conference on Solid Waste Research whose purpose was to stimulate research in the field. The long-range aspects of the solid waste management problem and the urgency of working toward a solution were recognized. The conference, held for 2½ days in December 1963, in Chicago, reviewed the solid waste problem in the United States. Some 36 papers and summaries were presented by authorities in the field.

The conference covered research needs in waste characterization, waste collection and transportation, and waste treatment and utilization. Efforts were directed toward encouraging young researchers to meet these needs.

The budget covered mainly travel and per diem expenses for program participants and study section members. Travel for 30 young researchers and for 3 foreign scientists, preparation and printing of the program, stenotype recording, and transcription and publication of the proceedings were also funded.

PUBLICATIONS

MCKINNEY, R. E. Proceedings; National Conference on Solid Waste Research, Chicago, Dec. 1963, University of Chicago Center for Continuing Education. Special Report No. 29. American Public Works Association, 1964. 228 p.

National Symposium on Animal Waste Management

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Ohio State University
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Grant No. SW 00026-01
Funds Awarded: $6,500
Project Period: Apr. 1, 1966 to Mar. 31, 1967

These funds supported, in part, a National Symposium on Animal Waste Management at Michigan State University, May 5 to 7, 1966. The conference was designed to appraise animal waste management needs and stimulate research on problems in the area. Another objective was to provide a forum for teams of scientists, engineers, public health officials, and others to exchange knowledge on agricultural waste problems. More than 300 persons attended the conference, including a number of foreign scientists.

PUBLICATIONS

Management of Farm Animal Wastes; Proceedings; National Symposium on Animal Waste Management, East Lansing, Michigan, May 5–7, 1966, Kellogg Center for Continuing Education, Michigan State University. ASAE Publication No. SP–0366. St. Joseph, Mich., American Society of Agricultural Engineers. 161 p.

National Industrial Solid Waste Management Conference

Dr. H. Nugent Myrick
Department of Environmental Science and Engineering
University of Houston
Houston, Texas 77004

Grant No. EC 00331-01
Funds Awarded: $29,500
Project Period: May 1, 1969 to August 31, 1970

OBJECTIVES: To develop and conduct a national conference on the management of industrial solid wastes. A multisession format included coverage of technical information on characterization, collection, processing, and reuse. Economic aspects and aspects of secondary-industry technology were considered.

APPROACH: The program was developed by a national task force committee representing industrial, professional, governmental, and research interests. The committee worked by mail, for the most part, and at any major technical meeting attended by a significant number of the committee members. The chairman made personal contacts with the pertinent major professional societies and trade associations to seek their support or cooperation. All technical papers were by request and represented the most rigorous evaluation of the current technology and state of the art. A conference proceedings will be published.

Design of a Water-Disposable Packaging Container

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Grant No. EC 00033–03
Funds Awarded: $163,500
Project Period: Mar. 1, 1968 to Feb. 28, 1972

OBJECTIVES: To develop a packaging container that, after use, can be easily processed to dissolve in water. The packaging containers being investigated consist of a water-soluble superstructure with a thin, impervious coating that resists corrosion by the environments commonly encountered in the packing industry. After the container has been emptied, it can be refilled if desired, or the coating can be broken so that the water-soluble superstructure can be dissolved.

Both organic and inorganic coatings are being tested. Sodium silicate glasses, potassium silicate glasses, alkali halides, peptide crystals, and sugar derivative crystals are being investigated as water-soluble superstructures. A three-step procedure for solid waste disposal is envisioned, as follows: crushing or grinding followed by incineration, followed by dissolution.

APPROACH: To accomplish these objectives, kinetic studies of the interaction between water-soluble glasses and aqueous solutions are being done. Kinetic studies of the interaction between "coated" water-soluble glasses and corroding media are also being made. Physical properties such as tensile strength, compressive strength, flexural strength, impact strength, fatigue strength, elasticity, and hardness of the "coated" water-soluble glasses before and after the corrosion tests are being investigated. The inorganic coatings are being applied by chemical vapor deposition and ion exchange procedures. The organic coatings are being applied by use of fluidized bed procedures. The effect of the coatings and water-soluble glasses upon the various biological systems of laboratory animals are being investigated to ensure that the container materials developed are nondeleterious to health.

FINDINGS: Soluble silicate glass compositions are readily coated by chemical vapor deposition processes. Metallic oxides derived from selected organic esters provide excellent coating materials for soluble glass substrates. The high vapor pressure and chemical stability of the mother liquid readily allow coatings to be produced by pyrolysis reactions at the heated substrate surface. Titanium oxide coatings are readily produced over a wide range of controlled conditions such as deposition temperature, time, carrier gas flow rate, reactant vapor concentration, substrate orientation, and others. The coatings produced can be amorphous or crystalline, depending upon conditions. These coatings are chemically stable and form a chemical bond with a glass substrate. Silicon oxide glass coatings are produced under somewhat more restricted conditions; however, the coatings formed likewise possess excellent properties. The problem of residual stress in the coated samples is a greater hazard with SiO_2 coatings because of generally higher deposition temperatures and a greater mismatch of thermal expansion coefficients.

The rendering of sodium silicate glass insoluble with H_2SO_4 in a displacement reaction involving participation by the sodium ions of the glass is a feasible method of producing a water-soluble packaging container. The H_2SO_4 treatment can be used to protect complicated shapes because the procedure is not critically sensitive to orientation of the substrate and distance from the input vapors. The resulting glass is transparent without any appreciable birefringence. The glass has an unusually high strength because of the compressive surface resulting from the chemical treatment. The glass fragments are similar to "safety" glass when mechanically ruptured and are thus readily dissolved when broken.

Sodium silicate glasses in the composition range 1.0 $Na_2O \cdot 1.3\ SiO_2$ to 1.0 $Na_2O \cdot 1.6\ SiO_2$ possess adequate strength and ease of workability to be used as materials of construction for containers.

The engineering feasibility of a water-soluble packaging container consisting of water-soluble sodium silicate glass superstructure with an inert barrier film deposited by either a chemical vapor displacement reaction or pyrolysis has been demonstrated. The feasibility of ultimately applying the technology derived from this investigation to the solution of container waste control problems is bright; however, these three basic questions have to be answered before the water-soluble container can become a reality: (1) What is the toxicology of the system? (2) What is the effect of the system on water quality? (3) What is the economic evaluation of processing procedures?

PUBLICATIONS

HULBERT, S. F., and C. C. FAIN. Water disposable glass container is a subject of Clemson U. research. *Midwest Engineer*, 21(9):10–11, May 1969.

HULBERT, S. F., C. C. FAIN, M. M. COOPER, D. T. BALLENGER, and C. W. JENNINGS. Improving package disposability. *In* Proceedings; First National Conference on Packaging Wastes, San Francisco, Sept. 22–24, 1969. Clemson, S.C., Clemson University. p. 147–179.

FAIN, C. C., S. F. HULBERT, and M. M. COOPER. Design of water-disposable packaging container. ASME Paper No. 69–WA/PID–16. Presented at Winter Annual Meeting, American Society of Mechanical Engineers, Los Angeles, Nov. 16–20, 1969. 5 p.

A Study of Farm Wastes

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Grant No. UI 00556–04
Funds Awarded: $138,345
Project Period: June 1, 1964 to May 31, 1969

OBJECTIVES: To study farm animal wastes in order to determine quality, physical character, chemical and biological composition, and the effects of animal-housing practices. To evaluate the economic value of farm wastes to agriculture, and any adverse effect such wastes may have on public health.

APPROACH: Wastes from dairy cows were collected periodically, weighed, and analyzed. Exploratory analyses of swine and poultry wastes were made and bacteriologic characteristics of fresh wastes from ruminating animals, lagoon waste input, and lagoon microorganisms were investigated. These studies include liquid manure wastes being held in below-ground storage tanks for removal to fields. In soils, farm wastes receiving different methods of treatment were compared by direct field application and laboratory greenhouses for their value in stabilizing soil structure and for their contribution to the nutrition of field crops. Sources and amounts of pollution of surface and subsurface waters resulting from various animal waste management and farming practices were studied. Odor abatement was investigated.

FINDINGS: Lagoons appeared to provide a means of waste reduction. The final conclusions checked with the laboratory results on this point. The reasons for less than 100 percent reduction became evident when studies on lignin indicated the durability of this type of compound.

The fate of intestinal-pollution types of bacteria were studied and found to follow the path of rapid reduction during waste treatment, either aerobic or anaerobic. Reduction was not, however, complete unless the effluent had been filtered through soil—the ultimate place of safe disposal for farm animal waste.

Publications

Witzel, S. A., N. A. Jorgensen, R. F. Johannes, H. J. Larsen, and C. O. Cramer. For loose-cow housing: Cold deep-bedded pack vs. cold free stalls. *Agricultural Engineering,* 48(2):86–88, Feb. 1967.

Witzel, S. A., E. McCoy, and R. Lehner. Chemical and biological reactions from lagoons used for cattle. *Transactions of the American Society of Agricultural Engineers,* 8(3):449–451, Nov. 20, 1965.

Witzel, S. A., E. McCoy, L. B. Polkowski, O. J. Attoe, and M. S. Nichols. Physical, chemical and bacteriological properties of farm wastes (bovine species). *In* Management of Farm Animal Wastes; Proceedings; National Symposium on Animal Waste Management, East Lansing, Michigan, May 5–7, 1966, Kellogg Center for Continuing Education, Michigan State University. ASAE Publication No. SP–0366. St. Joseph, Mich., American Society of Agricultural Engineers. p. 10.

McCoy, E. Lagooning of liquid manure (bovine): Bacteriological aspects. *Transactions of the American Society of Agricultural Engineers,* 10(6):784–785, Nov.–Dec. 1967.

Hoadley, A. W., E. McCoy, and G. A. Rohlich. Untersuchungen ueber *Pseudomonas aeruginosa* in Oberflaechengewaessern. I. Quellen. II. Auftreten und verhalten. [Investigations on *Pseudomonas aeruginosa* in surface waters. I. Springs. II. Occurrence and behavior.] *Archiv fuer Hygiene und Bakteriologie,* 152(4):328–345, Aug. 1968.

Hoadley, A. W., and E. McCoy. Some observations on the ecology of *Pseudomonas aeruginosa* and its occurrence in the intestinal tracts of animals. *Cornell Veterinarian,* 58(3):354–363, July 1968.

Minshall, M., M. S. Nichols, and S. A. Witzel. Plant nutrients in base flow of streams in southwestern Wisconsin. *Water Resources Research,* 5(3):706–713, June 1969.

McCoy, E., and W. B. Sarles. Bacteria in lakes: Population and functional relationships. *In* Proceedings; International Symposium on Eutrification: Causes, Consequences, Correctives, National Academy of Sciences, Madison, Wisconsin, June 11–16, 1967. Washington, 1969. p. 331–339.

McCoy, E. Removal of pollution bacteria from animal waste by soil percolation. ASAE Paper No. 69–430. Presented at Annual Meeting, American Society of Agricultural Engineers, Lafayette, June 22–25, 1969. 8 p.

Hensler, R. F., R. J. Olsen, S. A. Witzel, O. J. Attoe, W. H. Paulson, and R. F. Johannes. Effect of method of manure handling on crop yields and runoff losses. ASAE Paper No. 69–468. Presented at Annual Meeting, American Society of Agricultural Engineers, Lafayette, June 22–25, 1969. 16 p.

Gramms, L. C., L. B. Polkowski, and S. A. Witzel. Anaerobic digestion of animal wastes (dairy bull, poultry and swine). ASAE Paper No. 69–462. Presented at Annual Meeting, American Society of Agricultural Engineers, Lafayette, June 22–25, 1969. 26 p.

Disposal of Dairy Cattle Wastes by Aerobic Digestion

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Grant No. EC 00244–02
Funds Awarded: $113,098
Project Period: Jan. 1, 1967 to Dec. 31, 1969

Objectives: To determine the chemical composition, physical characteristics, and biodegradability of dairy cattle waste and to relate this information to the possible separation of various constituents of the waste so as to render certain portions of the waste more treatable by aerobic digestion. The composition of dairy waste was related to the rations of the cattle and in turn to the treatability. The treatability of cattle waste was determined with regard to loading rate, temperature, oxygenation rate, and oxidation characteristics.

Approach: Waste characterization and treatability studies were done for the most part in the laboratory. Field-acquired samples were diluted and put through a series of screenings, sedimentations, and filtrations with analysis of materials retained in each step. Based on these results, methods of pretreatment of livestock waste, including grinding, were developed. Subsequent to these studies pretreated waste in the laboratory was digested aerobically in chambers with the removal of sludge as required. BOD, COD, pH, volatile solids, and total solids were measured as often as necessary while temperature was varied to determine its effect on biodegradation rates. Concurrently, quantities of wastes produced were determined, and biological analysis was made to determine what differences in microorganism content of manures result from animals being fed antibiotics, stilbestrol, and other feed additives.

Findings: A 74-day experiment conducted at five different temperatures on blended (ground) cow manure gave the following reductions of volatile solids and CODs.

Temperature, F	*Percent reduction of volatile solids*	*Percent reduction of COD*
40.4	45.7	
47.9	46.7	43.3
56.2	58.5	57.8
64.8	71.4	80.8
74.7	78.6	83.7

A sharp change in the rate of decomposition of the volatile solids and COD seemed to occur between 45 F and 55 F. The chambers at higher temperatures, 56.2 F and above, also had smaller solids concentrations in the settled supernatant liquid. In an experiment on the aerobic storage of dairy cattle manure for 28 days at 4 C and 24 C and four loading rates, results were as follows. The holding temperature had a marked effect upon the degree of change that took place in the reactors. Approximately half as much of the constituents as measured by the volatile solids, COD, and Kjeldahl nitrogen were lost in the 4 C reactor as were lost at the higher 24 C temperature. The data show that nitrogen was lost from practically all the systems, but the concentration of nitrogen per gram of volatile was higher in the systems operated at both temperatures than at the higher temperature above, and it was the highest in the 4 C reactor. This indicates a lesser reduction of nitrogenous compounds at the lower temperatures.

In regard to the percent removals, the results of all tests shows that at 24 C the removals of volatile solids, COD, and Kjeldahl nitrogen were 42.3, 53.6, and 43.5 percent, respectively, and for the 4 C tests the removals of volatile solids, COD, and Kjeldahl nitrogen were 20.1, 24.5, and 15.9 percent, respectively.

The manure, both that fresh from the barnyard and that stored under refrigeration, was odorous and somewhat objectionable in the laboratory. No objectionable odors, however, were noted near the reactors at either of the two temperatures. An "earthy" odor, not unpleasant, was detectable within a foot of the units.

Foaming of the aeration units was a continuous problem. The foam was very stable and consequently difficult to control. More foam was produced by the 4 C units than by the 24 C units.

In another experiment the foaming characteristics of dairy cattle manure were studied during aerobic digestion. Both foaming tendency and foaming stability of raw manure slurries were significantly greater (99 percent confidence) at 4 C than at 20 C. A linear relationship was found between both foaming tendency and foaming stability and solids concentration of manure slurries ranging from 1,000 to 30,000 mg/liter. Foaming tendency increased with decreasing fineness modulus (particle size distribution). Foaming stability, however, was not affected by the level of fineness modulus. Foaming tendency increased with increasing solids concentration up to 15,000 mg/liter but not thereafter. Foaming stability was not affected by the solids concentration. The percent reduction in total volatile solids obtained in the digesters at 20 C varied from 30.0 to 34.9 percent for straight (nonblended) cow manure.

Another phase of the research investigated the possibility of storing dairy cattle manure at constant temperature (20 C) and loading 0.02 lb volatile solids per cu ft per day in a reactor with aerobic conditions in the top part and anaerobic conditions in the bottom part of the reactor. Results indicated the following.

1. Hydrogen sulfide was not produced during this type of storage.
2. Odors were minimized in aerobic-anaerobic storage of dairy cattle manure.
3. There were reductions of 26.2 percent in total solids and of 29 percent in volatile solids when unblended manure was used.
4. There were decreases in total Kjeldahl nitrogen and in COD.

In an experiment studying the effect of size of particles on decomposition rate of volatile solids in dairy cattle manure, there appeared to be a definite relation between them. The finer the particles the greater the rate of decomposition.

In an 87-day experiment on the disposal of dairy cattle manure by aerated lagoons and irrigation, the system appeared to be an excellent method for the disposal of dairy cattle wastes. Some of the following factors were evident in this experiment.

1. The system is essentially odorless (a slight ammonia odor was detected during loading).
2. The system provides a place to dispose of wastes at all times.
3. A large part of the nutrients is returned to the land.
4. With proper operation, runoff into streams and ditches is minimized.
5. Pollutional characteristics of all wastes are greatly lowered.
6. Costs of installation and operation do not appear to be excessive.
7. Relatively small amount of labor is required.

Irrigation removed 9 percent of COD, 11 percent of BOD, 14 percent of the volatile solids, and 23 percent of the total solids. Settling and decomposition by oxidation removed approximately 60 percent of COD, 70 percent of BOD, 55 percent of the volatile solids, and 35 percent of the total solids from the supernatant.

PUBLICATIONS

DALE, A. C. Aerobic treatment of animal wastes. ASAE Paper No. 67–927A. Presented at Winter Meeting, American Society of Agricultural Engineers, Detroit, Dec. 12–15, 1967. 7 p.

LUDINGTON, D. C., A. C. DALE, and D. E. BLOODGOOD. Storage of poultry manure with minimum odor. ASAE Paper No. 67–932. Presented at Winter Meeting, American Society of Agricultural Engineers, Detroit, Dec. 12–15, 1967, 19 p.

NYE, J. C., A. C. DALE, and D. E. BLOODGOOD. Effect of temperature on aerobic decomposition of dairy waste. ASAE Paper No. 69–926. Presented at Winter Meeting, American Society of Agricultural Engineers, Chicago, Dec. 9–12, 1969. 10 p.

Engineering Properties of Farm Wastes

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Grant No. EC 00297–03
Funds Awarded: $50,093
Project Period: June 1, 1966 to Dec. 31, 1969

OBJECTIVES: To develop techniques for measuring and evaluating some of the bio-engineering properties of farm wastes useful in the design of systems for the management of animal manures without creating environmental pollution or public nuisance.

APPROACH: Waste samples from chickens, dairy cows, beef cattle, pigs, and sheep were analyzed to determine pollution potential parameters. Standard tests on BOD, COD, moisture, and solids were made. In addition, data on quantities excreted with different food rations were determined. The composition of gases emanating from manure pyrolysis and also the odor characteristics of wastes under various conditions of storage were determined.

FINDINGS:

1. Odor nuisance is one of the most critical problems adversely affecting livestock and poultry producers. By means of an equilibration sampling technique, volatiles from dairy animal waste were concentrated into a form suitable for gas chromatographic analysis. An odor signature, the gas chromatogram with an organoleptic evaluation indicated for odorous peaks, was obtained for dairy waste decomposing anaerobically. Compounds tentatively identified as contributing to the odor were hydrogen sulfide, methanethiol, methyl sulfide, ethyl sulfide, propyl acetate, and n-butyl acetate.

2. Agricultural land is the best alternative for the disposal of animal wastes. By use of

a systems analysis approach, a scheduling model was developed for studying long-term scheduling decisions for removing animal waste from storage and spreading it on agricultural land. The maximum quantity that can be disposed, in each time period, is constrained by storage capacity, quantity of waste generated, and land area available for spreading. An air quality model was developed for evaluating the odor nuisance potential of animal wastes as a constraint on land spreading operations. The principal parameters affecting downwind ground level concentration of odors are emission rate, wind speed, diffusion coefficient, and turbulence index.

3. A menace from noxious gases exists in animal confinement units. It was determined that under normal operating conditions gases in confined animal houses do not reach toxic or lethal levels. Toxic level may be reached during failure of the forced ventilation system or as a result of mismanagement practices, such as agitating liquid manure storage under the building.

4. Combustion of animal manures is a possible unit operation in a waste management system. Animal wastes were pyrolyzed, heated to 800 C out of contact with air. Gases, water, and organic liquids were evolved, leaving a clear residue. The gases were analyzed for the percentage of CO_2, CO, H_2, illuminants (unsaturated hydrocarbon), methane, and ethane.

5. In the design of biological treatment units, values on the oxygen demand of the waste are essential. In the determination of the oxygen demand parameters of animal wastes, seeding, temperature, method of determination, and type of waste have a significant effect. Storage of samples at below 2 C does not have a significant effect.

6. In the design of waste management systems, a knowledge of the quantities of waste excreted by animals is essential. The quantities of the total excrement from animals are significantly affected by the feed, the weight of the animal, and the type of the animal. The total daily manure excrement varied from around 15 percent of body weight when cows were fed silage to 6 percent when they were fed corn and grass silage. Cow manure ranged from 13 to 53 percent of the feed intake per day.

PUBLICATIONS

Taiganides, E. P. Waste problem recognized; research help on manure disposal on the way. *National Hog Farmer*, 11(7):22–23, July 1966.

Taiganides, E. P. The animal waste disposal problem. *In* N. C. Brody, *ed.* Agriculture and the quality of our environment. Washington, American Association for the Advancement of Science, 1967. p. 385–394.

Taiganides, E. P., and T. E. Hazen. Properties of farm animal excreta. *Transactions of the American Society of Agricultural Engineers*, 9 (3):374–376, 1966.

Taiganides, E. P. Modern methods of animal waste disposal. *In* Proceedings: 27th Annual Meeting, Nutritional Council of American Feed Manufacturers Association, Chicago, May 22, 1967. p. 21–22.

Taiganides, E. P. The battle of the forgotten end. ASAE Paper No. 67–925. Presented at Winter Meeting, American Society of Agricultural Engineers, Detroit, Dec. 12–15, 1967.

Taiganides, E. P. Farm-waste management in Europe and India. *Agricultural Engineering*, 48 (12):710–713, Dec. 1967.

White, R. K. Gas chromatographic analysis of odors from dairy animal wastes. Ph. D. Thesis, Ohio State University, 1969. 143 p.

Taiganides, E. P. Mission impossible: dispose animal wastes. Presented at 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, May 6–8, 1969. 13 p.

White, R. K., and E. P. Taiganides. Malodors from dairy cattle wastes. ASAE Paper No. 69–425. Presented at Annual Meeting, American Society of Agricultural Engineers, Lafayette, June 22–25, 1969. 8 p.

Taiganides, E. P., and R. K. White. The menace of noxious gases in animal confinement units. Transactions of the American Society of Agricultural Engineers, 12 (3): 359–362, 367, May–June 1969.

Handling, Treatment, and Disposal of Animal Wastes

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Grant No. SW 00040-03
Funds Awarded: $74,019
Project Period: June 1, 1963 to May 31, 1966

OBJECTIVES: To determine the physical, chemical, and bacteriologic properties of hog wastes and to test methods for the management, treatment, and disposal of these wastes in order to reduce any health hazards or potential water pollution. Wastes from other farm animals were also studied but in less detail.

APPROACH: Lagoons and the resulting effluent received the greatest attention under various liquid and solid waste loadings. Anaerobic digesters and an oxidation ditch were also studied. Properties of raw manures and treated effluents were evaluated for total and volatile solids; specific weight; BOD; COD; nitrogen, phosphorus, and potash content; toxic substances; and other characteristics.

FINDINGS: An anaerobic lagoon loaded at a rate of 3.5 to 5 lb of volatile solids per 1,000 cu ft provided satisfactory preliminary treatment to liquid swine manure. Total solids were reduced by 75 to 80 percent; volatile solids, 85 to 90; COD, 85 to 90; BOD, 60 to 70; and total nitrogen, 45 to 50. The pH of this lagoon remained at 7.1 or above. Red-pigmented bacteria became established each summer, and this tended to reduce hydrogen sulfide odors. In spite of the pollutant removal, the effluent was unsuitable for discharge to a receiving stream.

A series of experimental anaerobic lagoons was used to determine the desirability of deep (10 ft) lagoons. To avoid occasional malfunctions, a swine manure loading rate of 5 lb of volatile solids per 1,000 cu ft was established. For swine wastes, a lagoon design criterion of 1.42 cu ft/lb of animal weight was proposed.

A heated-stirred anaerobic digester being used to treat swine manure, loadings of 20 lb of volatile solids per 1,000 cu ft were found operable. At higher loading rates, copper appeared to inhibit digestion. Gas, 60 percent methane, was produced at rates of 7.8 to 10.3 cu ft/lb of volatile solids. The digested solids were not attractive to flies and were free of offensive odors.

A mathematical model was derived and verified to predict the performance of an extended aeration plant treating lagoon effluent. BOD removal efficiencies in excess of 80 percent were obtained. The parameters of importance in determining treatment efficiencies were mixed-liquor volatile suspended solids, detention time, and influent quality.

In an evaluation of an oxidation ditch rotor at immersions of 6, 9, and 12 in. and speeds of 60 and 100 rpm, oxygen transfer rates of 2.3 to 17 lb/hr and 3.6 to 4.4 lb of oxygen per kw-hr were measured.

An exploratory study in which anaerobic lagoon effluent was applied to soil columns indicated the necessity for alternate periods of wastewater application and nonapplication to maintain acceptable permeability rates. Soil temperature was important in determining the rate of recovery of soil permeability.

PUBLICATIONS

TAIGANIDES, E. P., E. R. BAUMANN, H. P. JOHNSON, and T. E. HAZEN. Anaerobic digestion of hog wastes. *Journal of Agricultural Engineering Research* (London), 8(4): 327, 1963.

TAIGANIDES, E. P., E. R. BAUMANN, and T. E. HAZEN. Sludge digestion of farm animal wastes. Journal Paper No. J-4661, Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project No. 1433. Published, *Compost Science*, 4(2):26, Summer 1963.

TAIGANIDES, E. P. Agricultural solid wastes. *In* Proceedings; National Conference on Solid Waste Research, Chicago. Dec. 1963, University of Chicago Center for Continuing Education. Special Report No. 29. American Public Works Association, 1964. p. 39.

Taiganides, E. P., T. E. Hazen, E. R. Baumann, and H. P. Johnson. Properties and pumping characteristics of hog wastes. *Transactions of the American Society of Agricultural Engineers*, 7 (2):123, 1964.

Taiganides, E. P. Disposal of animal wastes. *In* Proceedings of the Nineteenth Industrial Waste Conference, Part One, Purdue University and Indiana State Board of Health, Lafayette, Indiana, May 5–7, 1964. *In* Engineering Bulletin of Purdue University, Engineering Extension Series No. 117, 49(1a):281–290, Jan. 1965.

Taiganides, E. P. Disposal of animal wastes. Journal Paper No. J–4876, Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa, Project No. 1433. 1964.

Taiganides, E. P. Theoretical considerations of anaerobic lagoons for poultry wastes. Journal Paper No. J–4889, Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project No. 1433. 1964. Published, Proceedings; Second National Symposium on Poultry Industry Waste Management, Lincoln, May 19–20, 1964, University of Nebraska Center for Continuing Education. p 251.

Taiganides, E. P., and T. E. Hazen. Properties of farm animal excreta. *Transactions of the American Society of Agricultural Engineers*, 9 (3):374–376, 1966.

Willrich, T. L. Primary treatment of swine wastes by lagooning. *In* Management of Farm Animal Wastes; Proceedings; National Symposium on Animal Waste Management, East Lansing, Michigan, May 5–7, 1966, Kellogg Center for Continuing Education, Michigan State University. ASAE Publication No. SP–0366. St. Joseph, Mich., American Society of Agricultural Engineers. p. 70.

Wallize, J. The story of a 'model'; swine in confinement. *Iowa Farm Science*, 22 (1):3, July 1967.

Miner, J. R., and T. E. Hazen. Alternatives to oxidation ditches under slotted floors. *In* Proceedings; Tenth National Pork Industry Conference, Lincoln, Nebr., Nov. 9, 1967.

Taiganides, E. P. Anaerobic digestion of poultry manure. *World's Poultry Science Journal*, 19(4):252–261, Oct.–Dec. 1963.

Identification of Odors in Feedlot Operations

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Grant No. UI 00531–02
Funds Awarded: $49,329
Project Period: Feb. 1, 1967 to Apr. 30, 1969

Objectives: To identify the odors associated with confinement livestock operations. To provide the analytical means for assessing the magnitude and possible effect of the odors on a community and for evaluating the effectiveness of modifying feedlot practices to reduce odors.

Approach: Gas chromatography with flame ionization or electron capture detection was the principal method used. Since the intensity of the odors from a real feedlot is heavily dependent on weather and the state of the feedlot, most of the analytical development was carried out on laboratory mixtures. An odor threshold test equipment was assembled and used to assess the intensity of odors.

Findings: Trimethylamine is a principal substituent in cattle feedlot atmospheres in concentrations well above its odor threshold of 0.6 ppb. Several experiments, including a simple odor comparison test, verified this. Limited results show that ethylamine or methylamine, propylamine, and butylamine are also present in concentrations above their odor thresholds. Ammonia and perhaps hydrogen sulfide or a mercaptan are present but in concentrations below their odor thresholds. Time did not permit a thorough analysis of fatty acids or alcohols. Amines proved especially difficult to handle in trace quantities because of their ready adsorption onto surfaces, but useful chromatographic methods were finally developed. Many techniques for sample collection and additional techniques such as paper chromatography were tested briefly.

Future work should include research in this area since acids are a product of decomposing protein as are amines. More information concerning odor thresholds of these odorants is also needed.

Livestock Waste Management and Sanitation

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Grant No. EC 00245–03
Funds Awarded: $96,894
Project Period: Sept. 1, 1966 to Feb. 28, 1970

OBJECTIVES: To refine knowledge of the physical, chemical, and biological properties of livestock wastes for the development of methods of waste treatment and management that meet the requirements of low labor and odor abatement, and pollution abatement. The project was principally concerned with swine waste management, but cattle wastes were investigated to a limited extent.

APPROACH: Primarily, field studies were conducted on the University of Illinois swine and beef farms equipped with liquid waste facilities, oxidation ditches, sandbed filters, and a series of lagoons. The buildings housing the hogs and beef cattle have self-cleaning slotted floors with liquid manure collection gutters beneath the floor. Laboratory studies supplemented the field studies when required.

The studies considered aspects of chemical treatment of liquid manure and an aerobic treatment process to suppress objectionable gases and odors. In the chemical treatment study, the type and amount of treating materials needed, and the management procedures for removing and using these solids were studied. In the aerobic biological study, design and operating criteria were developed. These included oxygenation characteristics of cage rotors, allowable concentrations of solids in the liquid, BOD loading rates, liquid velocity requirements to prevent settling, and ultimate disposal methods of surplus water and solids.

FINDINGS: The main chemicals studied for odor control were chlorine and lime. They were used to prevent the otherwise untreated anaerobic state of liquid manure beneath the animals and the resulting objectionable gases and odors. The chlorine acted as a bactericide and was very effective, even in amounts less than the organic matter's chlorine demand. The lime acted to control the pH in the 9 to 11 range that was considered too high for anaerobic bacterial action. This also worked, but the resulting release of ammonia at the high pH levels was very objectionable in the buildings. However, the costs of chemical treatment approached or exceeded estimated costs of biological treatment, and the organic matter was practically unchanged as a potential water pollutant. Thus, the chemical treatment method was abandoned in favor of aerobic biological treatment since the latter method held promise not only for odor control but also for significant reductions in the BOD.

The aerobic approach resulted in a livestock waste management system that very nearly satisfies the criteria of low labor cost, low odor, prevention of stream pollution, simplicity of operation, and economic feasibility. The system consists of an oxidation ditch beneath self-cleaning slotted floors in a confinement livestock building. Mixed liquor from the oxidation ditch flows by gravity to a nonoverflow aerobic lagoon (oxidation pond or aerated lagoon) having a fluctuating depth. Fields can be irrigated by surplus water and solids from the lagoon at a time that is convenient to the operator. This results in a system that is very low in labor cost and in odors from animal to field.

The in-the-building oxidation ditch is a completely mixed aerobic method having a long detention time (approximately 50 days). It is a modified form of the odorless "Pasveer" oxidation ditch treatment plant that was developed in the Netherlands.

Results of this project, both in laboratory and field trials, have shown the operating criteria of the in-the-building oxidation ditch to be as follows.

1. A ditch liquid volume of 30 cu ft/lb of daily BOD_5. Note, the loading BOD_5 is

in a very concentrated form (30,000 to 50,000 mg/liter instead of 300 to 500 mg/liter as in municipal oxidation ditches).

2. The liquid depth is shallow, usually less than 2 ft, to keep the solids suspended.

3. The aeration rotor should have an oxygenation capacity (as measured in clean water at standard conditions) twice that of the daily BOD_5 loading.

After coming to equilibrium, the ditch mixed-liquor BOD_5 will typically be 3,000 to 5,000 mg/liter, resulting in a 90 percent reduction of the BOD_5. Moreover, total volatile solids are reduced by about 50 percent. However, the effluent, even if the settleable solids were removed from the supernatant, is not suitable for direct discharge into a stream because of the color (reddish brown), the mineral content, and even the BOD. This is the reason for the nonoverflow aerobic lagoon and the irrigation system.

Several types of cage rotors were tested in clean water for oxygenation output. A typical value was 1.6 lb O_2/hr/ft at 6-in. rotor blade immersion and 100 rpm. Moreover, a related laboratory study resulted in establishing the amount of aeration required for given levels of odor production. The aeration rates ranged from excessive for the BOD down to no air in five steps.

Many livestock producers are adopting this waste treatment system, and at least two companies are manufacturing aeration rotors specifically for livestock oxidation ditches. The method does, of course, have inherent costs, the greatest being the power cost of operating the rotor. This may, however, be an attractive alternative to the producer faced with odor nuisance or complaints about stream pollution.

PUBLICATIONS

Hammond, W. C., D. L. Day, and E. L. Hansen. Can lime and chlorine suppress odors in liquid hog manure? *Agricultural Engineering*, 49(6):340–343, June 1968.

Day, D. L., and J. C. Converse. Oxidation ditch for swine waste. In Engineering Foundation Research Conference, Solid Waste Research and Development, University School, Milwaukee, July 24–28, 1967. Conference Preprint No. E–5. 3 p.

Day, D. L. Current status of the oxidation ditch; summary of United States and European research. Presented at Tenth National Pork Industry Conference, Lincoln, Nebraska, Nov. 9, 1967. 8 p.

Jones, D. D., B. A. Jones, Jr., and D. L. Day. Aerobic digestion of cattle waste. *Transactions of the American Society of Agricultural Engineers*, 11(6):757–761, Nov.–Dec. 1968.

Dale, A. C., and D. L. Day. Some aerobic decomposition properties of dairy-cattle manure. *Transactions of the American Society of Agricultural Engineers*, 10(4):546–548, 1967.

Day, D. L. Oxidation ditches combine well with slotted-floor hog setups. *Prairie Farmer*, 140(3):58, Feb. 3, 1968.

Day, D. L., J. C. Converse, and D. D. Jones. Rotor aeration of swine wastes. *Illinois Research*, 10(2):16–17, Spring 1968.

Jones, D. D., B. A. Jones, Jr., and D. L. Day. Aerobic digestion of cattle waste. *Transactions of the American Society of Agricultural Engineers*, 11(6):757–761, Nov.–Dec. 1968.

Jones, D. D., B. A. Jones, Jr., and D. L. Day. Aerobic digestion of cattle wastes. *Illinois Research*, 10(3):8, Summer 1968.

Day, D. L., D. D. Jones, and J. C. Converse. Field testing the oxidation ditch for swine waste. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, II, Beaver Dam, Wis. July 22–26, 1968. Conference Preprint No. E–4.

Day, D. L. Oxidation ditches for waste disposal. *International Journal of Farm Building Research*, 3:2–7, Dec. 1968.

Jones, D. D., D. L. Day, and J. C. Converse. Oxygenation capacities of oxidation ditch rotors for confinement livestock buildings. Presented at 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, May 6–8, 1969. 15 p.

Muehling, A. J., and D. L. Day. State regulation of lagoons. *Prairie Farmer*, 144(10):14, May 17, 1969.

Day, D. L., D. D. Jones, J. C. Converse, A. H. Jensen, and E. L. Hansen. Oxidation ditch treatment of swine wastes. ASAE Paper No. 69–924. Presented at Winter Meeting, American Society of Agricultural Engineers, Chicago, Dec. 9–12, 1969. 15 p.

Jones, D. D., D. L. Day, and U. S. Garrigus. Oxidation ditch in a confinement beef building. ASAE Paper No. 69–925. Presented at Winter Meeting, American Society of Agricultural Engineers, Chicago, Dec. 9–12, 1969. 10 p.

Microbiological Stabilization of Animal Wastes

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Grant No. UI 00519–03
Funds Awarded: $67,355
Project Period: June 1, 1964 to Nov. 30, 1967

OBJECTIVES: To study the stabilization of livestock wastes by microbial means and to determine the physical, chemical, and microbiological characteristics of these wastes, and the changes occurring to the point of stabilization. To obtain information that will give engineers design criteria for the kinds and sizes of processing equipment needed to convert this material into a less unsanitary state.

APPROACH: Measured quantities of animal excreta were placed in a stainless steel digester tank. Their stabilization was observed while oxygen supply, pH, temperature, and amounts of water were varied. The microbial flora were also studied in order to improve the stabilization rate. The biochemical oxygen demand (BOD) was determined at the start and end of the biox process to give a measure of the changes made and the degree of stabilization. The various gases produced, CH_4, CO_2, NH_3, H_2, and H_2S, were collected and measured.

FINDINGS: Anaerobic and aerobic microorganisms are necessary to reduce the BOD of animal waste to acceptable levels. Studies are underway to determine the organisms and their enzymes responsible for production of hydrogen sulfide and thio-alcohol during treatment of animal waste. Strength of animal waste has been related to human wastes.

PUBLICATIONS

BULLERMAN, L. B., and E. C. BERRY. Use of cheese whey for vitamin B_{12} production. II. Cobalt, precursor, and aeration levels. *Applied Microbiology*, 14(3):356, May 1966.

BULLERMAN, L. B., and E. C. BERRY. Use of cheese whey for vitamin B_{12} production. III. Growth studies and dry-weight activity. *Applied Microbiology*, 14(3):358, May 1966.

BERRY, E. C. Requirements for microbial reduction of farm animal wastes. *In* Management of Farm Animal Wastes; Proceedings; National Symposium on Animal Waste Management, East Lansing, Michigan, May 5–7, 1966, Kellogg Center for Continuing Education, Michigan State University, ASAE Publication No. SP–0366. St. Joseph, Mich., American Society of Agricultural Engineers, p. 56–58.

Poultry Manure Disposal by Plow Furrow Cover

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Grant No. EC 00254–03
Funds Awarded: $192,570
Project Period: Dec. 1, 1966 to Mar. 31, 1970

OBJECTIVES: To develop equipment and techniques for disposing of poultry manure in soil by the plow-furrow-cover (PFC) method and to determine the amounts, frequency of application, and length of time that poultry manure may be so disposed of without undesirable effects. To measure the chemical, physical, and biological changes occurring in the soils used and to determine the pollutional effects on the ground water.

Approach: Equipment was developed to permit the depositing of poultry manure in the soil by the PFC method. Poultry manure then applied to various experimental plots. Numerous hybrid sudan grass crops were grown in the second year. Lysimeters were used to collect percolation water at a 4-ft depth for analysis. In addition to the percolation water collected by the lysimeters, soil samples were taken at various times from three intermediate depths, and the extract was analyzed to determine the rate of percolation of contaminants.

Laboratory studies determined the maximum concentration of chicken manure that the soil could decompose without adverse effects. A manure loading was applied to the soil, and after a given percentage of the manure had decomposed, another loading of equal magnitude was applied, and so on, until the relative merits of the different loading regimes could be assessed. Selected soil characteristics such as organic matter content, texture, pH, fertility, exchange capacity, and water-holding capacity were evaluated before and after each experiment to provide information on the changes occurring in the soils.

Findings: To apply wastes by the PFC method, various components of equipment were developed and used in this project. In this method of waste disposal, slurries and semisolid wastes are incorporated into the aerobic layer of the soil in a relatively odor-free manner that does not attract flies and other pests. It involves depositing the waste in a 6- to 8-in.-deep plowed furrow and immediately covering it. The covering operation provides the next furrow into which the waste is deposited.

Poultry manure was PFC applied into test plots of Freehold loamy sand (B horizon of 20 percent clay) in amounts equivalent to 0, 15, 30, and 45 tons of dry solids per acre. This is only half of the stated application rate. An initial application of 0, 15, 30, and 45 tons was planned for the *surface* during winter months; however, because of the danger of stream pollution from surface runoff, this application was not made. Because of the slow downward movement of the elements in the soil, crops were not planted, and the variable of plant takeup in observing the rate of downward movement of elements was thereby avoided. Soil water was sampled with suction lysimeters, and soil samples were collected. Samples collected 131 days and 17 in. of rainfall after the PFC application showed a downward movement of Ca, Cl, K, Mg, Na, $NO_3{}^+NO_2{}^-N$, and SO_4 to a depth of 36 in. Samples collected 391 days and 50 in. of rainfall after the PFC application showed considerable increase in element concentration at the 36- and 48-in. depths. The dissolved nitrogen (N) in the soil water, totaled for the soil depth from 9 to 48 in., was 20, 186, 526, and 1,026 lb/acre for the four application rates of 0, 15, 30, and 45 tons of dry solids per acre. The maximum concentration was 700 ppm nitrogen (N). Disposal of these large amounts of poultry manure in soil caused large increases in the concentrations of elements in the soil water down to a depth of 48 in.

The pollution potential to ground water was also investigated. Percolation water was collected 48 in. below ground surface by means of zero-tension lysimeters. Data for fecal coliform and total organic carbon (TOC) were obtained in addition to the elements previously listed. After 7 months there was no significant difference in the TOC concentrations for the several application rates (loadings). The lack of positive fecal coliform tests with the relatively small nitrate and sulfate concentrations tend to indicate no detrimental effects to the ground water 7 months after the PFC application. However, 12 to 15 months after the application some very large nitrate, sulfate, and TOC concentrations were measured in the ground water. This corresponds to the large increase in the concentration of elements noted in the soil water to a depth of 48 in.

Laboratory experiments were conducted to evaluate the effect of variables on the rate of decomposition (as measured by CO_2 evolution) of excreta mixed with soil. The absolute amount of CO_2 evolved was greatest at the higher loadings (up to soil:excreta= 1:1), but the percent decomposition of added excreta was greatest at the lower loadings (down to 10:1). Temperature (4, 12, and 20 C) had little effect on the rates of CO_2

evolution at the lower loading regimens. Successive increments of excreta decomposed about as rapidly as the original addition. At low loadings, soil texture had little effect, but at higher loadings decomposition was fastest in the lighter soils tested. A salt concentration equivalent to about eight excreta applications at the low rate inhibited decomposition only slightly.

Any method of disposing of chicken excreta should take into account the possible presence of substantial numbers of Salmonellae, which are human pathogens. Approximately 30 percent of the excreta samples obtained from commercial farms for these decomposition studies contained *Salmonella*.

PUBLICATIONS

KRAFT, D. J., C. OLECHOWSKI-GERHARDT, J. BERKOWITZ, and M. S. FINSTEIN. Salmonella in wastes produced at commercial poultry farms. *Applied Microbiology*, 18 (5): 703–707, Nov. 1969.

Sanitary Engineering Applied to Livestock Manures

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Grant No. EF 00265-04
Funds Awarded: $59,875
Project Period: Sept. 1, 1961 to Aug. 31, 1965

OBJECTIVES: To develop sanitary and effective methods of processing and disposing of the manure produced on concentrated livestock farms such as dairies, beef feed lots, and poultry farms. To develop improved methods of collecting and transporting manure from the point at which it is defecated by the animal.

APPROACH: Extensive laboratory and pilot plant operations of various processing and stabilization techniques—solids digestion, manure lagoons, algae ponds, composting, and drying—were conducted to develop manure management methods feasible at the farm level. Ultimate disposal techniques and outlets were evaluated. The overall research concept was that the most feasible end disposal would be agricultural land.

FINDINGS: From the farmer's viewpoint, lagoons can be made to work, but underground water pollution is a definite hazard, odors are likely, and costs are not as low as farmers desire.

Research was also done on digestion of manure, and its limitations of cost and ultimate disposal of the digested sludge were determined. Composting as a method of manure processing was found to be less than satisfactory at the farm level.

The greatest potential for proper management of most livestock manure appears to be via variations in the natural drying process. The summer-arid climate of California can be taken advantage of, and systems of storing manure during the winter are possible. Drying was accomplished by "thin spreading" or by mechanically tilling and agitating foot-deep beds of manure.

The results of this research have been applied by California farmers, and the state of wastes management practices has benefited from the research effort.

PUBLICATIONS

HART, S. A. Digestion tests of livestock wastes. *Journal of Water Pollution Control Federation*, 35(6):748, June 1963.

HART, S. A. Fowl fecal facts. *World's Poultry Science Journal*, 19(4):262, Oct.–Dec. 1963.

OSTRANDER, C. E., and S. A. HART. Degradation of manure collected in water under chickens. *Poultry Science*, 43(5): 1144, Sept. 1964.

HART, S. A. Thin spreading of slurried manures. *Transactions American Society of Agricultural Engineers*, 7(1): 22, 1964.

HART, S. A., and W. C. FAIRBANK. Disposal of perished poultry. *In* Proceedings, Second National Symposium on Poultry Industry Waste Management, Lincoln, May 19–20, 1964, University of Nebraska Center for Continuing Education. p. 213.

HART, S. A., and M. E. TURNER. Poultry manure lagoons. *In* Proceedings, Second National Symposium on Poultry Industry Waste Management, Lincoln, May 19–20, 1964, University of Nebraska Center for Continuing Education.

HART, S. A., and M. E. TURNER. Lagoons for livestock manure. *Journal of Water Pollution Control Federation*, 37(11):1578, Nov. 1965.

HART, S. A., and C. G. GOLUEKE. Producing algae in lagoons. *Transactions of the American Society of Agricultural Engineers*, 8:122, Nov. 1965.

HART, S. A., and M. E. TURNER. The design of waste stabilization ponds for the treatment of agricultural wastes. Paper presented at lecture series on Advances in Water Quality Improvement, Austin, Apr. 4–7, 1966. The University of Texas.

HART, S. A., J. A. MOORE, and W. F. HALE. Pumping manure slurries. *In* Management of Farm Animal Wastes; Proceedings; National Symposium on Animal Waste Management, East Lansing, Michigan, May 5–7, 1966, Kellogg Center for Continuing Education, Michigan State University. ASAE Publication No. SP–0366. St. Joseph, Mich., American Society of Agricultural Engineers. p. 34.

A Recirculating Waste System for Swine Units

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Grant No. EC–00283–02
Funds Awarded: $40,717
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To perfect a recirculating water-waste-handling system using existing facilities and consisting of an anaerobic lagoon and an oxidation ditch. A laboratory waste treatment pilot plant is being operated in such a way as to simulate a recirculating waste treatment plant so that operational and design criteria can be determined. Management implications such as cleanliness of pens, growth rate of swine, and social order are being studied as well as optimum method of operation so as to avoid adverse effects on the animals' and the operators' health.

APPROACH: Samples of the influent and effluent from the waste treatment systems (an anaerobic lagoon and an aerobic oxidation ditch) and the recirculating water are analyzed for their chemical, physical, and biological properties, namely, COD, BOD, solids, coliform, enterovirus, pH, and chlorides. All the animals are examined routinely for symptoms of disease related to the waste-handling system. Specific animal tests, which have previously been designed, are used to determine the influence of the handling system on the health and growth rate of the animals. Odor, temperature, and humidity are measured in the confinement area, and the laboratory-scale waste treatment pilot plant is operated so as to permit evaluation of the overall effectiveness of the proposed recycle-water carriage-manure system.

FINDINGS: A recirculating hydraulic manure transport system is in operation. Manure is removed from the 700-head swine confinement building by hourly flushing 100 gal of water into the two shallow gutters traversing the animal pens. The water flows down 42-in. wide by 2-in. deep gutters, carrying with it manure accumulated since the previous flushing. The animals have responded to this system by depositing all feces and urine in the gutter, and this keeps the remainder of the pens dry and free of manure. When flushing occurs, the pigs move to the gutter for diversion and provide the necessary agitation to suspend the manure solids in the flushing water. The result is a confinement building in which no manual manure removal is necessary and in which there is a decidedly lower odor level than in comparable buildings with other means of manure collection.

No pen washing or other cleaning efforts are used.

From the building the manure and water flow by gravity into an anaerobic lagoon that effectively removes the solids and reduces the organic content of the liquid wastes. Effluent from the lagoon is pumped to an oxidation ditch for further removal of organic matter and control of odor. After settling to remove solids, the oxidation ditch effluent is pumped back to the flush tanks in the confinement building for reuse. The waste treatment system produces an effluent of acceptable quality for reuse within the building, has not resulted in disease problems within the building, and has eliminated the need to haul manure or to discharge effluent into the receiving stream.

Construction currently underway will allow wastewater from the building to be diverted directly to the oxidation ditch. In this mode of operation, the lagoon will be used as a disposal method for excess solids from the oxidation ditch. Other aspects of the system will be unchanged.

Soil used as a means of disposal for excess lagoon effluent is applied at rates up to 3 in. per application at intervals of 3 to 5 days. This high loading rate is managed to promote maximum nitrogen removal and results in essentially complete removal of organic matter, phosphorus, and bacteria while removing 60 to 70 percent of the nitrogen. Detailed studies of nitrogen transformations and changes in the soil's organic matter are underway.

PUBLICATIONS

MINER, J. R. A review of the literature of 1967 on wastewater and water pollution control. Industrial wastes. Agricultural (livestock) wastes. *Journal of the Water Pollution Control Federation*, 40(6):1150–1158, June 1968.

HAZEN, T. E. Wiles of wet wastes. ASAE Paper No. 68–556. Presented at Winter Meeting, American Society of Agricultural Engineers, Chicago, Dec. 10–13, 1968. 10 p.

KOELLIKER, J. K., and J. R. MINER. Use of soil to treat anaerobic lagoon effluent: Renovation as a function of depth and application rate. ASAE Paper No. 69–460. Presented at Annual Meeting, American Society of Agricultural Engineers, Lafayette, June 22–25, 1969. 19 p.

HAZEN, T. E., and J. R. MINER. Waste-environment complex in confinement production of swine. *In* Proceedings; Seventh International Congress of Agricultural Engineering, Baden-Baden, Germany, Oct. 6–9 1969. [St. Joseph, Michigan, American Society of Agricultural Engineers.] p. 197–203.

WILLRICH, T. L., and J. R. MINER. Anaerobic lagooning of swine wastes *In* Proceedings; Seventh International Congress of Agricultural Engineering, Baden-Baden, Germany, Oct. 6–9, 1969. [St. Joseph, Michigan, American Society of Agricultural Engineers.] p. 287.

MINER, J. R. A review of the literature of 1968 on wastewater and water pollution control. Industrial wastes. Agricultural (livestock) wastes. *Journal of the Water Pollution Control Federation*, 41(6):1169–1178, June 1969.

MINER, J. R. The universities' role in feedlot pollution control. *In* Proceedings; Animal Waste Management Conference, Kansas City, Missouri, Feb. 1969. U.S. Federal Water Pollution Control Administration. p. 23–25.

SMITH, R. J., T. E. HAZEN, and J. R. MINER. Piggery cleaning using renovated wastes. Presented at Symposium on Farm Wastes, University of New Castle Upon Tyne, England, Jan. 7–8, 1970. 25 p. (Iowa Agriculture and Home Economics Experiment Station Journal Paper No. J6435, Iowa State University.)

MINER, J. R., and T. L. WILLRICH. Livestock operations and field-spread manure as sources of pollutants. Presented at Conference Concerning the Role of Agriculture in Clean Water, Iowa State University, Ames, Nov. 18–20, 1969. (Iowa Agricultural and Home Economics Experiment Station Journal Paper No. J–6378.)

MINER, J. R., E. R. BAUMANN, T. L. WILLRICH, and T. E. HAZEN. Pollution control—feedlot operations. *Journal of the Water Pollution Control Federation*, 42(3):391–398, Mar. 1970.

Effects of Processing Poultry Manure on Disease Agents

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Grant No. EC 00316–02
Funds Awarded: $63,596
Project Period: June 1, 1968 to May 31, 1970

OBJECTIVES: To investigate the survival of disease agents in composted and dried poultry wastes and the spread of the agents from conventional versus composted and dried

waste products removed from poultry houses. To determine the effects of variants in management during the composting and drying of poultry wastes of different origin on the chemical, physical, and pathogenic nature of the end products.

Approach: Manure produced by domestic chickens, turkeys, and quail were studied to determine the effects of species, sex, age, management, nutrition, and environment on the physical, chemical, and pathogenic nature of the raw manure. The various types of manure were then either composted or dried by using some of the major variations of management in processing that are likely to affect the end product. The physical properties (particle size, density, storage stability, etc) and chemical properties (pH, moisture, nitrogen, calcium, phosphorus, etc) of the treated manure were determined. During the processing several parameters such as temperature, humidity, and an air pollution potential were monitored. The use of various litter material such as shavings, sawdust, rice hulls, corn cobs, peanut hulls, and straw was studied to determine their effect on the composted product.

Litter scheduled for composting and manure scheduled for drying were seeded with various pathogens associated with poultry to determine the effect of the management of the two processes on the survival of these pathogens. Specific pathogens studied included the following: Fowl pox virus, Infectious Brusal Agent, *Clostridia* sp, *Pasteurella Multocida*, *Aspergillus flavus*, *Aspergillus fumigatus Eimeria* sp, *Ascaridia* sp, *Raillietina Cesticillus*, Musca domestica, *Bdellonyssus sylviarum*, and Darlking beetle.

Findings:

1. *The limitations of laboratory composting of poultry wastes* have been clearly demonstrated. It is necessary to have adequate volume in order to simulate field conditions. The results obtained from small units are highly suspect, at least 100 bird units being necessary to provide adequate volume of wastes for working each treatment.

2. *Disease carryover in composted poultry wastes.* Studies with Coccidia, Salmonella, and Newcastle virus seeded in litter prior to composting indicate reduction in active pathogens. Owing to overlong composting resulting from inadequately sized litter piles, the same reductions in pathogen numbers were obtained with time. It is essential therefore to have sufficiently large piles of manure during composting in order to obtain adequate heating.

Results from the past 2 years' studies indicate that several species of bacteria and viruses are not suitable for a variety of reasons for studying the carryover of disease agents in poultry wastes. Coccidia and nematodes appear to be the best agents with which to work, especially since these agents are not highly contagious. Techniques developed to control these agents would probably be effective for others since these organisms are relatively difficult to control.

3. *Ultraviolet irradiation of poultry manure* has been indicated to have distinct possibilities in controlling the carryover of disease organisms.

4. *Poultry litter materials and composting.* It is possible to compost poultry litter consisting of any organic matter that has been tried including corn cobs, rice hulls, peanut hulls, straw of various kinds, sawdust, hard and soft wood shavings, and so forth. The environmental conditions prevailing represent the main factor affecting speedy heating, provided adequate air, moisture, and carbonaceous and nitrogenous materials are present.

5. *Physical properties of wastes in relation to composting.* The particle size must be fairly uniform and small for the best composting. Too fine particle size causes anaerobic compaction, and overly large particle size permits too much air to penetrate the pile. Mineral content of poultry manure within the usual limits has no apparent effect on composting, and pH is highly variable within and between piles that have supposedly been subjected to similar treatments.

6. *Drying poultry wastes.* Provided a temperature of some 200 F is reached for a few minutes, pathogens evaluated appear to be destroyed. Incinerators therefore provide a disease-free material but produce air pollution. Dryers usually well exceed 200 F and

should therefore also provide disease-free processed poultry wastes. Mork work is required to evaluate further the time-temperature factor with more pathogens.

7. *Reduction in the volume of poultry wastes.* Traditionally all floor-raised commercial poultry-broilers, turkeys, most replacement pullets, and many layer flocks are raised on fresh floor litter. By composting the litter between broods it has been demonstrated that the heat treatment controls most active pathogens, and the volume of litter required by the poultry industry has therefore been greatly reduced. This is of economic benefit to the poultry industry, especially as competition increases for sugar cane wastes, wood shavings, and other absorptive materials.

From the standpoint of the volume of poultry solid wastes it is estimated that 90 percent of the broilers and many of the turkeys raised during the past 2 years in the United States have been raised on recycled litter, and the volume of solid wastes for disposal has thereby been vastly reduced. Furthermore, the resulting stabilized organic wastes do not pollute soil, water, and air when distributed on the land as raw manure does.

8. *Manure from caged poultry.* Because of labor shortages and economics many poultrymen are presently being forced to automate their layer operations by caging their birds. Aerobic digestion of caged layer poultry manure has been economically established and is now being used on a limited scale in the United States to combat fly and odor problems. Aerobic digestion will control these problems and has enabled some harassed poultry operators to remain in business. In addition the volume of the manure has been greatly reduced, and furthermore stabilized organic material eliminates soil, water, and air pollution.

9. *Cages for broilers.* Classically, broilers are raised on floor litter to avoid the development of breast blisters and leg deformities. Recent studies under this grant have shown that broilers may now be raised successfully in plastic-floored cages without these problems. If the cage system is adopted by the poultry industry for raising broilers, and it could well be the case, the volume of solid wastes produced by broilers in the United States could be further vastly reduced since no litter would have to be used. The feces could also be digested under these cages to reduce volume, control fly and odor problems, and stabilize the material in order to avoid odor, fly, and pollution problems when the material is used in horticulture and agriculture.

10. *Composting of cattle feedlot wastes.* Although outside the limits of the grant, assistance has been given to a feedlot operator in Texas to compost feedlot wastes. A pilot operation has been highly successful in producing a reduction in volume and has resulted in an odorless, stabilized agricultural fertilizer.

11. *Composted garbage for poultry litter.* Garbage from which metal, glass, paper, rags, and plastic had been removed was composted by Lone Star Organics, Inc, of Houston. The resultant material has been evaluated as an absorbent poultry litter and found to be highly desirable. Large-scale field trials are now in progress.

PUBLICATIONS

Howes, J. R. Methods of disposal; poultry wastes. *Texas Agriculture Progress*, 14:22–23. 1968.

Howes, J. R. Management and utilization of poultry wastes. *Feedstuffs*, 40(50):22–23. 1968.

Howes, J. R. The digestion of poultry feces under cages. *Poultry Science*, 47(5):682. Sept. 1968. (Abstract.)

Howes, J. R. How to manage poultry waste. *Canadian Poultry Review*, 93(3):11–12, 38–39, Mar. 1969.

Howes, J. R. A review of available litter materials and their advantages and disadvantages. *In* Proceedings, Third National Poultry Litter and Waste Management Seminar, 1969. p. 140–149.

Howes, J. R. The composting of poultry manure and litter and its use as a garden and feed fertilizer. Presented at Pennsylvania Poultry Waste Conversion Symposium. Lancaster, 1969.

Howes, J. R., and J. W. Bradley. Composting garbage for poultry litter. Proceedings; Association of Southern Agricultural Workers, 66:257, 1969. (Abstract.)

Howes, J. R., and J. W. Bradley. Litter materials and management for broilers. *Poultry Science*, 48(5):1822. Sept. 1969. (Abstract.)

Howes, J. R., B. C. Wormeli, and B. R. Stewart. Cages as environment for broilers. *Poultry Science*, 48(5):1822, Sept. 1969. (Abstract.)

Research on an Animal Waste Pollution Control System

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Grant No. EC–00390–01
Funds Awarded: $52,048
Project Period: Aug. 1, 1969 to July 31, 1972

OBJECTIVES: To investigate the possibility of rendering animal wastes innocuous by steam drying and to determine the nutritional value of the dried wastes in hopes that they can be used as animal feed.

APPROACH: Three areas of investigation are associated with this research effort, as follows: the drying of the animal waste, characterization of the odors in the dried waste, and toxicologic and nutritional studies of the dried waste. The drying studies are being conducted on 1- to 5-lb samples of manure. Factors being determined include the effect of moisture content of manure on drier operation, the effect of mass velocity on both heat transfer and mass transfer, the influence of superheat in the drying medium (steam), the mechanism of drying, the influence of bed depth, effects of particle size and shape, and the influence of nozzle orientation. Both organoleptic testing or subjective evaluations and analytical testing by means of gas-liquid chromatography, infrared spectroscopy, and mass spectroscopy quantitatively and qualitatively define the odors present in the dried manure and the liquid waste resulting from the drying operation.

Toxicologic studies involve many chemical tests, including pH and alkalinity, and the contents of iron, phosphate, nitrate, sulfur, chloride, water- and ether-soluble materials, and nitrogen. Animal feedings are used to determine the toxic effects of the dried manure. Those products found nontoxic are evaluated for nutritive value by being fed to rats.

FINDINGS:

1. *Equipment.* An apparatus for conducting through-circulation drying tests with superheated steam or with mixtures of superheated steam and an inert gas has been designed, built, and put into operation. The equipment is suitable for the following limits on the drying parameters:

bed depth up to 9 in.
superficial fluid velocity up to 1,000 ft/min
gas temperature to 350 F
degrees of superheat to 140 F
any mixture of superheated steam with an inert gas

Provision for measuring drop, flow, and temperature, is incorporated in the system. A Sanborn two-channel recording system provides for continuous record of gas and pellet temperatures at several locations throughout the bed. A two-stage electrical heater and superheater supplies the energy for drying. The exhaust vapor is continuously condensed in a two-stage cooler-condenser system. Building supply steam, suitably reduced in pressure, is the drying medium.

2. *Experimental results.* Preforming and drying tests on cow manure obtained from the University of Delaware Agricultural Station are in progress. Results thus far indicate that a suitable preformed particle for through drying can be produced. Pressure drop and viscosity studies ae likewise in progress.

3. *Theoretical results.* A general computer simulation of the through-circulation drying process has been developed. The mathematical model considers the case in which a constant-rate drying wave advances through the bed in the direction of steam flow and is followed by an expanding falling-rate drying zone. The system of coupled nonlinear partial differential equations describing temperature and moisture content distribution in fluid and solid phases is solved by means of an explicit finite-difference technique.

The results of the simulation study are being applied to the optimization of the drying operation.

Survival of Pathogens in Animal Manure Disposal

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Grant No. EC 00302-02
Funds Awarded: $73,342
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVE: To determine the survival and subsequent public health hazards of pathogenic bacteria in cattle manure when disposal is by means of extended aeration. Laboratory models are used to determine the effect of specific field environmental conditions and chlorination upon the survival of *Leptospira pomona* and *Salmonella typhimurium*. Concurrently, the detection methods for these pathogens are being compared and evaluated.

APPROACH: Two laboratory-scale models of the extended aeration ditch were designed and constructed. One model is used for pathogen survival studies and the other for establishing engineering design criteria before its effect on pathogen survival is evaluated. Field environmental conditions, including humidity, dissolved oxygen, pH, and temperature, are duplicated in the laboratory model for pathogen survival studies. Known amounts of *L. pomona* and *S. typhimurium* are added to the mixed fecal liquor in the laboratory-model system, and samples of mixed liquor, sludge, and effluent are collected during periods of seeding and postseeding to determine the length of survival. Survival of pathogens is also studied in chlorinated effluent and holders immersed in the mixed liquor.

FINDINGS: The department is using a 1:10 laboratory-scale model of an operational field ditch. In the field ditch the department of agricultural engineering is studying the treatment of manure from beef cattle, housed under confined conditions. The field ditch is used for storage and treatment and receives manure from 36 beef cattle. After 6 months, animals are removed, ditch residues pumped, and new tests begun. Observed biological, chemical, and physical data indicate a system with a capacity of 50 cu ft per animal can store and treat such wastes through the Minnesota winter period.

The operational laboratory model has been developed and is being used to simulate field environmental conditions in order to study survival and detection of seeded pathogenic bacteria in beef cattle manure obtained from the field oxidation ditch. Improved methods of measuring survival and detecting eptospires in the manure have been developed by the use of fluorescent antibody and artificial cultural isolation techniques. Repeated survival studies have been conducted in the manure environment of Selas porcelain candles, which allow a nutritional exchange with the liquid media of the laboratory ditch. Studies have been conducted under simulated field conditions with varied pH, dissolved oxygen, temperature, and total solids. Recovery of leptospires has been culturally made up to several days following seeding. Leptospires have been detected by the fluorescent antibody techniques for longer periods of time. Studies are being conducted in manure effluents and sludge-scale models of settling chambers under varying environmental conditions. Leptospiral survival has been measured for several days and detection for longer periods. These findings indicate that a definite potential health hazard exists for man and animals.

The department of agricultural engineering is using another laboratory-scale model of the oxidation ditch. Studies are being made to define solid settlement patterns and the feasibility of the ditch as a means of separating undigested feedstuffs having nutritional value for reuse. The laboratory model has been used as an effective tool on changes in rotor design to control excessive foaming and effect oxidation capacity.

PUBLICATIONS

SOLAC, R. B. Survival of pathogens in animal manure disposal. *Veterinary Medicine Reporter*, No. 24:1ff., Dec. 1969.

Bacterial Contamination from Hospital Solid Wastes

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Grant No. EF 00007–04
Funds Awarded: $147,473
Project Period: Sept. 1, 1959 to Dec. 31, 1963

OBJECTIVES: To study the microbial hazards involved in solid waste handling and associated housekeeping procedures in hospital areas. To develop and demonstrate solid waste-handling methods designed to minimize airborne and contact contaminations in a hospital environment.

APPROACH: The investigation was conducted in a 753-bed teaching and research hospital and a 265-bed private general hospital. Detailed surveys, made of 5 solid waste categories at 15 service areas, provided information on the types of materials in each waste category and on generation, routes, and methods of transport from source to ultimate disposal. Waste-handling activities were simulated under laboratory conditions where background contamination could be controlled to measure bacterial dissemination. Tracer organisms were also used to determine actual distances under which microorganisms could be transported through the hospital after dispersal into the environment.

Air was extensively sampled in the 15 services and in waste-handling areas such as trash and laundry chute terminal points, trash and laundry storage areas, laundries, and incinerator rooms. Efforts were made to devise and demonstrate remedial measures to reduce bacterial contamination emanating from hospital solid wastes.

FINDINGS: Perhaps the most revealing finding was the great complexity of the total waste-handling operation. The facts that handling methods vary even within a particular service and that usually no single person in the hospital can detail all the waste-handling procedures attest to this complexity. Nevertheless, the survey identified the types of materials being discarded and helped to pinpoint some of the likeliest contamination-generating activities for evaluation of microbial dissemination. It also yielded a detailed record of exactly how the various solid waste materials are actually handled in a hospital, pinpointed some basically unsound procedures, and suggested improvements.

The need for a highly standardized method of air sampling of microorganisms was demonstrated for any attempt to compare areas or situations. Ventilation patterns, movement and direction of air, and details of temperature and humidity were all shown to be necessary adjuncts to a sampling program. Care in selecting the sampling location—preferably locations—within an area, based on knowledge of air movement, was indispensable. The sequential sampling technique (a series of samples taken over an extended period), together with a detailed record of activities in the area, was shown to be necessary for describing meaningfully the airborne microbial pattern of any area. With this method, it was possible to obtain quantitative data comparing many areas of the two hospitals and to demonstrate fluctuations in these levels related to specific activities, ventilation differences, and housekeeping procedures. It was shown that airborne contamination levels could be kept low (less than 10/cu ft) by strict attention to personnel and traffic control, together with properly designed ventilation systems and adequate housekeeping practices. Sharp increases in air counts were also detected, particularly those related to soiled-laundry-handling procedures. By means of microbial "tracers" the paths of dissemination of contamination related to waste handling and to other activities were tracked through the hospital.

It proved extremely important to standardize the method of surface sampling of microorganisms. The very high variability on most surfaces called for collection of very large sample sizes and the randomization of sampling sites to describe adequately the surface contamination of any area at a given time. The partial working out of a detailed method as part of the project was a major step toward adequately evaluating environmental surface contamination.

Another achievement was the development of a mass characterization procedure applicable to microbes isolated from the environment. With this procedure, data were obtained concerning types as well as numbers of environmental organisms; this information is of vital importance in determining the potential significance of microbial contamination. Application of this procedure demonstrated, for instance, that areas having the smallest numbers of organisms tended to have larger percentages of gram-positive cocci associated with dissemination from people; "dirtier" areas had larger percentages of dust-associated bacilli and molds.

Studies of remedial measures produced the following with regard to:

1. Laundry handling practices. Airborne contamination resulting from the emptying of loose linen from chutes added an average of 150 colonies/cu ft to the air near the chute opening, and increased counts fourfold or fivefold, even on the fourth floor (near the chute door). It was found that this contribution of contamination could be reduced by almost 75 percent by confining the linen in impervious bags and by almost 50 percent by adequate ventilation of the chute. It was also found that dissemination on upper floors could be prevented by ventilation that maintained negative pressure in the chute.

2. Environmental contamination in animal surgery. A special area was set up in which cleaning and disinfection, personnel dress, and traffic (but not ventilation) were rigidly controlled and compared with a similar area where there were no such controls but where the same surgical team could perform identical procedures on dogs. The air-sampling data collected for some 34 complete days in each area revealed that, despite the lack of ventilation control, the "sterile" area maintained a mean count of less than 20 colonies/cu ft of air compared with more than 70 in the other area. Autogenous factors in the dogs themselves prevented an accurate determination of infection rates related to environmental contamination. However, deaths from infection among all dogs in the "sterile" area approximated 24 percent compared with a 50 percent rate among dogs in the uncontrolled area. This suggests that a relationship to environmental contamination exists.

None of the evaluated cleaning methods or products consistently reduced the microbial count by as much as 80 percent immediately following the cleaning procedure. The count on the floor built up in proportion to the amount of new traffic and activity in the area, regardless of method or product used, and continued to rise until the day's activity ended. No significant difference could be determined between various germicidal products and control solutions using a nongermicidal detergent or ordinary hot tapwater. Wet-vacuum pickup reduced the microbial count slightly more than a standard mop-and-bucket system did.

PUBLICATIONS

GREENE, V. W., R. G. BOND, and G. S. MICHAELSEN. Air handling systems must be planned to reduce the spread of infection. *Modern Hospital*, 95(2):136, Aug. 1960.

GREENE, V. W., D. VESLEY, R. G. BOND, and G. S. MICHAELSEN. The engineer and infection control. *Hospitals (JAHA)*, 34(17):69, Sept. 1960.

GREENE, V. W. and L. G. HERMAN. Problems associated with surface sampling techniques and apparatus in the institutional environment. *Journal of Milk and Food Technology*, 24(8):262, Aug. 1961.

VESLEY, D. and M. BRASK. Environmental implications in the control of hospital-acquired infections. *Nursing Outlook*, 9(12):742, Dec. 1961.

GREENE, V. W. and D. VESLEY. Method for evaluating effectiveness of surgical masks. *Journal of Bacteriology*, 83(3):663, Mar. 1962.

GREENE, V. W., D. VESLEY and K. M. KEENAN. New method for microbiological sampling of surfaces. *Journal of Bacteriology*, 84(1):188, July 1962.

GREENE, V. W., D. VESLEY, R. G. BOND, and G. S. MICHAELSEN. Microbiological contamination of hospital air. I. Quantitative studies. *Applied Microbiology*, 10(6): 561, Nov. 1962.

GREENE, V. W., D. VESLEY, R. G. BOND, and G. S. MICHAELSEN. Microbiological contamination of hospital air. II. Qualitative studies. *Applied Microbiology*, 10(6): 567, Nov. 1962.

MICHAELSEN, G. S. Waste handling. *In* Proceedings; National Conference on Institutionally Acquired Infections.

Minneapolis, Minnesota, Sept. 4–6, 1963. Public Health Service Publication No. 1188. Washington, D.C., U.S. Government Printing Office, 1964. p. 65.

VESLEY, D. Surface sampling techniques for the institutional environment—present status. *In* Proceedings; National Conference on Institutionally Acquired Infections, Minneapolis, Minnesota, Sept. 4–6, 1963. Public Health Service Publication No. 1188. Washington, D.C., U.S. Government Printing Office, 1964. p. 101.

MICHAELSEN, G. S. and D. VESLEY. Industrial clean room versus hospital operating rooms. *Air Engineering*, 5(9):24, Sept. 1963.

VESLEY, D. and G. S. MICHAELSEN. Application of a sampling technique to the evaluation of bacteriological effectiveness of certain hospital housekeeping procedures. *Health Laboratory Science*, 1(2):107, Apr. 1964.

BULLOCK, W. E., J. W. HALL, W. W. SPINK, L. J. DAMSKY, V. W. GREENE, D. VESLEY, and H. BAUER. A staphylococcal isolation service: epidemiologic and clinical studies over one year. *Annals of Internal Medicine*, 60(5):777, May 1964.

MICHAELSEN, G. S. and D. VESLEY. Dissemination of airborne microorganisms in an institutional environment. *In* Surface Contamination; Proceedings; Symposium, Gatlinburg, Tennessee, June 1964. B. R. Fish, ed. Oxford, Pergamon Press, [1967]. p. 285

VESLEY, D., and G. S. MICHAELSEN. A technique for measurement of microbial contamination on flat surfaces. *In* Surface Contamination; Proceedings; Symposium, Gatlinburg, Tennessee, June 1964. B. R. Fish, ed. Oxford, Pergamon Press, [1967]. p. 321.

BOND, R. G., and G. S. MICHAELSEN. Bacterial contamination from hospital solid wastes. Minneapolis, University of Minnesota, Aug. 1964. 160 p.

Incineration of Infectious and Radioactive Solid Waste

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Grant No. EF 00579–01S1
Funds Awarded $52,122
Project Period: Feb. 1, 1964 to June 30, 1965

OBJECTIVES: To investigate and analyze the performance characteristics of a new institutional incinerator-boiler facility designed to dispose of combustible, infectious, and low-level-radioactive biological solid wastes from research laboratories and hospitals.

APPROACH: Harvard University's incinerator-boiler was used to investigate its use for disposal of solid waste from research operations and hospitals. Low-level-radioactive solid waste incineration and decontamination were also studied.

FINDINGS: The performances of a crematory-type incinerator and a combination steam-boiler incinerator were compared in the combustion of difficult laboratory and hospital wastes such as animals and cage litter. Because of excessive stack emissions of smoke, fly ash, and malodorous gases and vapors, the crematory type proved unsatisfactory. Under the most favorable operating conditions for avoidance of air pollution and for production of a good-quality residue, burning capacity was only 2 to 3 lb sq ft/hr. Higher burning rates produced severe nuisances. The mechanized steam-boiler incinerator, on the other hand, provided a sanitary method of handling and burning these wastes efficiently and rapidly. A cyclone dust collector proved superfluous for use with gas or oil fuels; it could be eliminated without decreasing the overall collection efficiency of an electrostatic precipitator that served as a final cleaning stage. Viable bacteria originating from the charge placed on the hearth of a crematory-type incinerator were recovered in the flue gases whereas the flue gases from the combination steam-boiler incinerator were always sterile.

PUBLICATIONS

FIRST, M. W., P. FILLES, and J. WALKLEY. Disposal of low level radioactive waste in commercial incinerators. *In* Proceedings of the Ninth AEC Air Cleaning Conference, Jan. 1967. p. 570–585.

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Hospital Solid Waste Disposal in Community Facilities

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Grant No. EC–00261–04
Funds Awarded: $110,630
Project Period: June 1, 1966 to May 31, 1970

OBJECTIVE: To define the solid waste problems of hospitals as they relate to design and operation of hospitals, to determine the impact of hospitals' solid waste on community facilities and operation, and to identify environmental health and safety problems associated with present practices in hospitals and their host communities.

APPROACH: During the first year of this investigation five hospitals were surveyed to determine the waste disposal practices qualitatively and quantitatively. Two were in a large city having a relatively sophisticated method of waste collection and disposal. These two were of different types and sizes to provide different waste characteristics. Another two hospitals were selected from suburban communities where waste collection and disposal programs were less developed. These two also were of different design and operation. The fifth hospital was in a rural area where there were further differences in design and operation and in the community's solid waste management.

After survey techniques and investigative procedures had been developed during the first year, 25 hospitals of different sizes and types in various communities around the country were studied during the second year. During the third year, the survey expanded to about 100 hospitals. Again, these hospitals were in different size communities and in different geographical locations, were of various sizes, and provided various services. The fourth year was devoted to the evaluation of data, development of recommendations, and publication of survey findings.

FINDINGS: Data are being analyzed, and discussion of specific findings would be premature. Findings are expected, however, to include the following:

An analysis of quantities of solid wastes from hospitals, indicating relation to number of beds, patient census, numbers of staff and students, number of outpatients, hospital facilities, community setting, and other factors.

Classifications of quantities of solid wastes from hospitals according to source within the hospital, type of solid waste, and method of disposal.

Listings of the problems arising at hospitals from on-site solid waste storage, treatment, and disposal, including compaction, incineration, grinding, bulk receptacles, and other items.

Descriptions of conditions found at community facilities receiving hospitals' solid wastes. The implications these conditions have for hospitals' solid waste disposal.

PUBLICATIONS

BOND, R. G., and A. F. IGLAR. Hospital solid waste disposal in community facilities. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, Milwaukee, July 24–28, 1967. Conference Preprint No. D–3.

MICHAELSEN, G. S., and A. F. IGLAR. Disposing of disposables. Presented at Annual Meeting, American Hospital Association, Chicago, Aug. 21–24, 1967. 8 p.

Study of Institutional Solid Wastes

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Grant No. EC 00265-02
Funds Awarded: $120,037
Project Period: Apr. 1, 1968 to Mar. 31, 1971

OBJECTIVES: To characterize solid wastes qualitatively and quantitatively from the West Virginia Medical School, which consists of a general hospital, a basic sciences building, and an animal quarters. In addition to the usual parameters used to describe, classify, and characterize solid wastes, considerable attention is being given to the possible contamination of such material by viruses and bacteria. Sampling procedures were developed to permit classification and identification of the solid wastes according to source and to the particular producing unit. It is believed that such information will be useful in establishing safe procedures for the handling of wastes exposed to pathogenic organisms and in providing a basis for the design of handling and disposal facilities.

APPROACH: The waste from the basic sciences building is collected from each floor and each significant unit and put into labeled bags. The hospital waste is collected and identified by grant personnel placed at the deposit points on each floor. Waste brought to the deposit points is placed by the observer in a properly tagged or colored bag and dropped in a chute to the incinerator room. Carcasses and combustible material in the animal quarters are incinerated. Carcasses harboring pathogenic organisms are autoclaved prior to incineration. It is felt that with the exception of a few microbiologic and virologic determinations, a physical description of solid waste from the animal quarters is adequate.

The waste from each unit is analyzed physically for weight, volume, and bulk density and classified into 14 different categories such as paper, cotton, and bottles. The waste is chemically studied for carbon, protein, phosphorus, nitrogen, carbon-nitrogen ratio, sulfur, and hydrogen as well as for pH, moisture, liquid content, volatile solids and ash, and gross and net calorific values. Biological studies include total count, total anaerobic count, aerobic and anaerobic spore formers, coliform count, staphylococci, beta hemolytic organisms, enterococci, viruses, and fungi. Survival of microorganisms in solid waste is also studied by sampling composite waste held at room temperature for different lengths of time.

FINDINGS: The annual production of solid wastes from the hospital and basic sciences building is approximately 1,000 tons. This is being classified according to the amount produced by departments, to the amount per bed in the hospital, and to other unit quantities.

A cost analysis of waste handling gave a cost of $77.30 per ton of waste handled.

A virologic study indicated that viruses could live in solid waste materials for approximately 3 to 5 days.

PUBLICATIONS

ZEPEDA, F. Statistical analysis of institutional solid wastes. Problem report submitted to the Graduate School, West Virginia University, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering. Morgantown, 1969. 59 p.

ARMSTRONG, D. Refuse chute sanitation. Problem report submitted to the Graduate School, West Virginia University, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering. Morgantown, 1969.

A Study of Incinerator Residue

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Grant No. UI 00509–03
Funds Awarded: $226,000
Project Period: Jan. 1, 1965 to Dec. 31, 1968

OBJECTIVES: To study incinerator residue of rotary kiln units and rocker-grate units, and incinerator residue from municipalities not having separate collection. To make a laboratory study by subjecting residue to tidal surging so that leaching and time release mechanisms could be studied.

APPROACH: Residue samples were screened to a 2-in. diameter and magnetically separated, and the nonmagnetic portion was shredded and milled. They were then analyzed for fats or oil-soluble fractions, water-soluble fractions, ignition residue, nitrogen, phosphorus, potassium, and occasionally, heavy metals. Odor, dust, and other nuisances were observed as well as fly and rodent attraction and breeding.

The effects of altering operating parameters such as feed rate, overfire and underfire air, and rate of grate travel on residue were investigated. Bed temperature must be high enough to decompose all organic material so that rat and fly breeding is not supported. An attempt was made to correlate stack gas temperature, residue bed temperature, and the organic content of the byproduct residue.

The effect of tidal surging through incinerated residue placed in a varying water table was investigated to determine if residue is suitable from a public health standpoint for waterfront reclamation. The filled area was chemically analyzed for information on the time release mechanism of leachable contaminants. Lysimeter studies and analysis of water-soluble fractions were used.

FINDINGS: The character of incinerator residue is determined by the degree of burnout, which may be estimated by the weight loss on ignition. Residue with greater than 90 percent burnout does not react biochemically, and the major leaching problem is from inorganic compounds. Major inorganics include chloride in concentrations of 2,000 mg/liter, sodium in concentrations of 3,500 mg/liter, and phosphate in concentrations greater than 10 mg/liter. In addition, the total dissolved solids are increased to 8,000 to 10,000 mg/liter.

For a landfill receiving only residue of less than 90 percent burnout, temperatures of decomposition were 140 F. This indicates that an incompletely burned residue will decompose similarly to unburned refuse.

Rates at which leaching occur are deceptive and vary with the component. For example, iron is quickly oxidized, and the concentration of iron in landfill leachate decreases rapidly. Conversely, the chloride and sodium concentrations are slower to develop, but they persist longer.

Effects of operation on character of residue indicate that most incinerators are not constructed with sufficient operating flexibility. Greater variation in total excess air and in the overfire/underfire ratio should be included. By altering retention time and bed temperature the degree of burnout can be increased.

PUBLICATIONS

PURDOM, P. W. Characteristics of incinerator residue. *In* Proceedings of the First Annual Meeting of the Institute for Solid Wastes of the American Public Works Association, Chicago, Sept. 13–15, 1966. p. 38–43.

PURDOM, P. W., and R. J. SCHOENBERGER. Incinerator residue. Limitations on use? Presented at Meeting, American Public Health Association, San Francisco, Nov. 2, 1966. 9 p.

SCHOENBERGER, R. J., and P. W. PURDOM. Classification of incinerator residue. *In* Proceedings; 1968 National Incinerator Conference, New York, May 5–8, 1968. American Society of Mechanical Engineers. p. 237.

SCHOENBERGER, R. J., N. M. TRIEFF, and P. W. PURDOM. Special techniques for analyzing solid waste or incinerated residue. *In* Proceedings; 1968 National Incinerator Conference, New York, May 5–8, 1968. American Society of Mechanical Engineers. p. 242.

Schoenberger, R. J., and P. W. Purdom. Residue characterization. *Journal of the Sanitary Engineering Division,* Proc. ASCE, 95 (SA3):387–397, June 1969.

Suffet, I., A. A. Fungaroli, R. J. Schoenberger, and S. J. Levy. Specific ion electrodes analysis of wastewaters from solid waste disposal. *In* Proceedings; Third Mid-Atlantic Industrial Waste Conference, College Park, Md., Nov. 12–14, 1969. University of Maryland. p. 279–303.

Schoenberger, R. J., P. W. Purdom, S. J. Levy, and H. I. Hollander. Characterization and treatment of incinerator process waters. *In* Proceedings; 1970 National Incinerator Conference, Cincinnati, May 17–20, 1970. New York, American Society of Mechanical Engineers. p. 204–215.

Smokeless Incineration of Bulky Municipal Refuse

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Grant No. EC 00248–05
Funds Awarded: $163,984
Project Period: Feb. 1, 1964 to Jan. 31, 1970

Objectives: To develop engineering data necessary for the design of incinerators for burning oversize solid waste. To determine an optimum time for consumption along with minimum emission of smoke, fly ash, and noncombustible residue.

Approach: An existing experimental bulky waste incinerator was modified and tested to determine optimum conditions for combustion of oversize wastes. Factors determined included the temperature of inlet air, refractories, and exit gases; drafts and draft losses; exit gas composition; capacity of exit gases; and airflow rates. The weight losses of the charges, gas composition, heat releases, and drafts were then plotted for the entire burning cycle. The volumes and densities of the initial charge and final residue were determined and weight and volume reduction ratios established.

A number of bulky waste incinerators around the country were studied in less detail and their characteristics evaluated with respect to performance.

Recommendations were prepared for the sizes of flue gas passages, volume and configuration of the primary and secondary chambers, types and thickness of refractory, and optimum width and height of the charging door.

Findings: A simple incinerator furnace has been evolved, without moving grates or stoking mechanism, and without the need for shredding the refuse. Bulky waste is deposited by dump truck in front of the charging door and charged by tractor.

The charges are burned on a refractory floor in a firebrick chamber. Air is supplied through ports in the floor, side walls, and arch. Logs, tires, demolition lumber, furniture, mattresses, and other materials burn until consumed in minutes or hours, depending on their thickness. Additional charges can be added as space becomes available by the burning down of previous charges. Simplicity permits use of semi-skilled labor. Fifteen to eighteen lb are burned hourly per sq ft of hearth area.

Combustion of gases and smoke from the primary furnace is completed in the secondary chamber. Although the amount of fly ash (dust) in gases is small because of conservative rates of burning, flue gas-cleaning equipment (scrubber, electrostatic precipitator) can be added to clean gases to any degree required.

The final report (in preparation) will provide basic design information and performance to be expected. At least two full-scale bulky refuse incinerators based in part on these principles have been built (Stamford and Norwalk, Connecticut) since preliminary findings became available.

The findings are expected to result in more installations across the country, at considerable saving over other types of incinerators. Landfill volume for residue is less than 10 percent that for unburned refuse.

Publications

KAISER, E. R. The incineration of bulky refuse. *In* Proceedings; 1966 National Incinerator Conference, American Society of Mechanical Engineers, New York, May 1–4, 1966. p. 39–48.

KAISER, E. R. A new incinerator control meter is needed. *In* Proceedings; 1966 National Incinerator Conference, American Society of Mechanical Engineers, New York, May 1–4, 1966, p. 176–182.

KAISER, E. R. The incineration of bulky refuse. II. *In* Proceedings; 1968 National Incinerator Conference, New York, May 5–8, 1968. American Society of Mechanical Engineers. p. 129–135.

KAISER, E. R. Successful incinerators are not cheap. *Power*, 113 (9):78–79, Sept. 1969.

KAISER, E. R. The mounting problem of solid wastes. *Power*, 113 (10):62–63, Oct. 1969.

Systems Analysis of Shipborne Municipal Incineration

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Grant No. UI 00557–04
Funds Awarded: $455,163
Project Period: Mar. 1, 1965 to June 30, 1969

OBJECTIVES: To investigate the scientific and technical aspects of ocean burning of municipal solid wastes, including demolition materials, and the disposal of residues at sea. The effect of residue disposal upon the chemical water quality, as well as upon living things, was considered as well as the effect of such incineration on the air.

APPROACH: Incinerator residues from land-based operations were chemically and biologically analyzed to establish their composition and their beneficial and detrimental effects on marine life. The deposition, distribution, and floating characteristics of ash released on surface water over a 1- to 2-sq-mi dumping area were investigated. An ecologic study was made to establish the effects of continuous shipborne incinerator operations on marine life. Moreover, meteorologic studies in the coastal area determined diffusion of stack discharges.

Methods of stabilizing solid wastes for storage up to 7 days were studied so that small coastal communities could collect and store refuse in a sanitary manner until sufficient quantities have accumulated to warrant an incinerator ship stop. Systems analysis was used to establish optimum refuse collection, location of dockage areas, quantity of refuse to be transferred per ship stop, and the optimum balance among the incinerator ship's burning, traveling, and loading times.

FINDINGS: Typical municipal incinerator residues contain 23 to 52 percent by weight of particles less than ½ in. in size. Larger particles are mostly metal cans and other large metal objects, glass bottle fragments, and stones. The biologically more active ½-in. or less fraction was used for bioassay studies, and the more visible, larger fraction for studies of residue stability on the ocean floor. Heavy-metal concentrations in the less than ½-in. fraction of residue ranged from 10 ppm for Cd and 60 ppm for Cr to 40,000 ppm for Fe. Lead content was 700 to 10,000 ppm with an average of 4,000 ppm for six different incinerator residues, but the fraction soluble in sea water was less than 1 percent of the total and often below detectable levels.

Bioassays conducted with winter flounder, quahaug, mummichog, shrimp, menhaden, lobster and lobster larvae, mullet, and sea scallops failed to demonstrate acute toxicity associated with incinerator residues when marine organisms were exposed to residue concentrations of 1 percent by weight or less in sea water. Twice weekly additions of residues to harbor pens containing quahaug for 37 months showed lower mortality and higher growth rates for residue-treated clams and more favorable responses from those treated with larger applications. The explanation is believed to be related to a coarsening of the silty bottom and the addition of nutrients from the residue. Similar long-term studies on winter flounder showed no excess mortality after 7 months. No concentration of heavy metals was observed in any species.

Direct observations of residue behavior on the ocean bottom at depths up to 200 feet over periods of many months while it was under the continuing influence of open ocean currents and wave action generated by storms indicated extreme stability of the deposited material. Following a violent autumnal storm, the maximum distance a half-gallon can was observed to have moved was 50 ft from its original deposition site after having remained motionless for the entire summer and early fall. Repeated surveys indicated that fish life was markedly attracted to the experimental dump sites.

Meteorologic studies have shown the great steadiness of the wind over the coastal waters even when wind speed is moderately high and have demonstrated the probability that for any weather pattern at least one satisfactory burning site can be found within a 10-mile run from shore that will not produce air pollution on land. Climatologic studies indicate that the annual frequency of days unsuitable for sailing an incinerator vessel having the characteristics of a Liberty ship is 5, whereas for a towed-barge operation the number of unsuitable days approaches 20. Waste management during periods of unfavorable weather can be by central storage at dockside, on-site storage by waste producers, dockside incineration using gas-cleaning devices and tall stacks, or land burial sites reserved for these periods.

The New York City Planning Commission has been studying ship incineration and has come to the conclusion that costs will be only slightly greater than for current disposal practices. Engineering studies of burning equipment and materials-handling equipment suitable for seagoing incinerator vessels indicate that the limitless oceanic heat sink may be utilized as a basis for designing alloy steel water-wall burning chambers without heavy and fragile refractory linings that might be damaged by the constant motion of a ship. The principles of containerized handling of ship's cargo appear to be suitable for waste handling and easily adaptable to incinerator ship requirements.

Manpower requirements will be a major cost item in the operation of a seaborne incinerator, even with a towed incinerator vessel. Recent developments in on-line computer operation of chemical and petrochemical manufacturing plants and electrical generating stations suggest the application of this concept to the operation of an incinerator with a minimum number of men. It would be possible to place incinerators on unmanned towed vessels or barges, and the associated automatic control systems on the tow vessel.

PUBLICATIONS

SILVERMAN, L. Incineration of solid wastes at sea. *APWA [American Public Works Association] Reporter*, 31:2, 4, July 1964.

OVIATT, C. A. The effects of incinerator residue on selected marine species. *In* Proceedings of the Annual Eastern Regional Antipollution Conference, Kingston, July 22–24, 1968. University of Rhode Island. p. 108–110.

FIRST, N. W. Waste incineration at sea and ocean disposal of non-floating residues. Presented at 62nd Annual Meeting, Air Pollution Control Association, New York, June 8–12, 1969. Paper No. 69–33.

Combustion Products from the Incineration of Plastics

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Grant No. EC 00386–01
Funds Awarded: $40,452
Project Period: Aug. 1, 1969 to July 31, 1972

OBJECTIVES: To analyze the combustion products of various polymers, and formulations made from these polymers, under a variety of conditions of temperature and air supply. Of primary interest are polystyrenes, polyethylenes, polysulfones, and polycarbonates. In addition, previous work on polyvinyl chloride, polyphenylene oxide, and polyimide is being reported from the standpoint of incineration problems. Some combustion runs are being done with secondary burning so that both complete and incomplete incinerator conditions are approximated.

APPROACH: A study of the mechanism of thermal decomposition of a plastic is being undertaken by using differential thermal analysis (DTA) and thermogravimetric analysis (TGA). From this information it is being determined whether the plastic breaks down in one continuous step or in a series of steps and also whether the reactions involved are exothermic or endothermic.

A combustion furnace with controlled temperature and air supply is being used to generate decomposition products for qualitative and quantitative analysis. The products are being collected and analyzed by gas chromatography, infrared and mass spectrometry, and other analytical methods. Temperature, airflow, heating rates, and open flame are being investigated as variables in the amount of products obtained from certain plastic formulations.

FINDINGS: Research on combustion products of plastics since July 1969 has included continuation of work on two plastics, polyphenylene oxide and polyimide, which was underway before the start of this grant, as well as preliminary studies on two new plastics, polycarbonate and polysulfone.

On thermal decomposition polyphenylene oxide was found to give large amounts of carbon monoxide, carbon dioxide, and straight-chain and aromatic hydrocarbons as volatile products. In addition, under our combustion conditions, a large amount of residue (~50 percent) as a viscous liquid containing high-boiling phenols and water was formed.

Polyimide undergoes the most nearly complete combustion of any plastic material tested under the research project's combustion conditions. Seventy percent of the plastic is converted to carbon dioxide and carbon monoxide on heating to 800 C. Water, ammonia, oxides of nitrogen, cyanogen, hydrogen cyanide, benzonitrile, and benzene have also been identified. Current work is on quantitatively accounting for the nitrogen in this plastic, which, because of the toxicity of the cyanides and nitrogen oxides, is extremely important. No single analytical technique has proved suitable for quantitation of these products, and a combination of gas chromatography and wet methods is being used.

Work on polycarbonate includes differential thermal analysis and thermogravimetric analyses showing a two-step decomposition, the first corresponding to a depolymerization and the second to formation of carbon dioxide and carbon monoxide from the remaining carbon skeleton. In addition to these two major products, methane, benzene, and toluene have been identified. Many more volatile compounds are unidentified. As with polyphenylene oxide, polycarbonate forms a viscous liquid residue accounting for about 50 percent of the weight of plastic burned. In addition to water, the major components of this residue are phenol, p-cresol, and p-ethylphenol.

We have also analyzed the combustion products of two plasticizers, diisodecyl phthalate and dioctyl phthalate, commonly used in PVC. Pyrolysis of these plasticizers results in breakdown into a solid, liquid, and gas phase. The gas phase consists of CO_2, CO, hydrocarbons through the butanes, and some oxygenated compounds. The liquid phase represents nearly pure plasticizer, which boils off, plus some water. The solid phase, composed of long, white, needle-like crystals, has been identified as phthalic anhydride, water, and the chain of the ester that is further decomposed into hydrocarbon fragments.

A modified combustion tube has been designed to allow insertion of two small flames at the outlet of the combustion furnace to provide secondary burning and to parallel more closely some types of incinerator combustion. This modification is being evaluated, especially with respect to its ability to combust the large amounts of liquid residue from polyphenylene oxide and polycarbonate.

Continuous-Feed Incineration of Municipal Refuse

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Grant No. EC 00251–04
Funds Awarded: $154,221
Project Period: Sept. 1, 1965 to Aug. 31, 1970

OBJECTIVES: To obtain fundamental engineering data needed for better design of continuous-feed solid waste incinerators. Test methods were developed to determine the variability of refuse composition; to determine the optimum proportions of overfire and underfire air; to determine heat release and transfer in the burning refuse, furnace, and waste heat boiler; to evaluate the refractory surfaces; and to determine the types and amounts of air and water pollution resulting from the operation of the Oceanside Refuse Disposal Plant in Hempstead, Long Island.

APPROACH: Full-scale tests were undertaken on the Oceanside Refuse Disposal Plant. Test methods were generally adopted from those used in the combustion of fuels and water analysis, or were developed in other cases. Samples of refuse taken at random intervals were reduced in size and analyzed. The variation in moisture in the flue gas was monitored and related to the moisture total in the refuse. The undergrate airflow was measured for each of the three windbox zones. The flow rate through each of the numerous overfire air nozzles was determined, and the optimum proportion of overfire air to underfire air was determined over a period of time at given loads by general performance, such as good burnout of the residue, balanced furnace temperatures, and freedom from smoke. The items for the heat balance were determined by measurement and calculation, both input and output. Residue output was determined on a total weight basis, and samples were analyzed for completeness of burning. Thermocouples in the furnace walls and gas-sampling probes were used to gather pertinent information. Gas samples were generally analyzed by Orsat apparatus, occasional samples being analyzed by mass spectroscopy and other techniques to determine the presence of minor constituents.

FINDINGS: Typical compositions and analyses of household refuse were determined for winter and summer conditions. Paper and paper products comprise almost 50 percent of the total, while glass/ceramics and metals are each about 9 percent. The average refuse is 28 percent moisture, 22 percent noncombustibles, and 50 percent combustibles, mainly cellulose. Detailed chemical analyses were run. The calorific value, averaging 4,500 Btu, results from partial oxidation of metals.

The combustion process is only partly completed in the fuel level; hydrocarbons evolved from the refuse must be burned in the furnace space. Overfire air jets are essential for this purpose. New design data on nozzle sizing, air pressure, and jet penetration have been reported in the publications listed below.

A simple system for calculating the heat and material input and output of incineration has been developed that is useful in calculating performance, heat losses, and so on.

By tests on a 300 ton-per-day furnace the temperature limits and mechanism for slag adhesion on refractory walls were established, as well as the means for preventing slag buildup. The refractory wall must be cooled to 1,200 F or lower to prevent glass from adhering.

Incinerator boiler tubes were eroded because fly ash acted as an abrasive when moving more than 20 ft/sec through a boiler tube bank. Corrosion of boiler tubes was also observed as the result of deposits on the tubes as well as of flame impingement. The mechanisms of fireside boiler tube wastage will be summarized in the final report. Waste heat boilers out of view of the flames at other incinerators have operated for years without these problems.

Recommendations for furnace design to achieve more nearly complete combustion are being formulated as a result of the project. Implementation of these recommendations will reduce smoke emission, carbon in fly ash, and emissions of unburned gases, vapors, and particles to the atmosphere.

PUBLICATIONS

KAISER, E. R. A new incinerator control meter is needed. *In* Proceedings; 1966 National Incinerator Conference, New York, May 1–4, 1966. American Society of Mechanical Engineers. p. 176–182.

KAISER, E. R. The sulfur balance of incinerators. *Journal of the Air Pollution Control Association*, 18(3):171–174, Mar. 1968.

KAISER, E. R., and W. B. TRAUTWEIN. Prevention of fused deposits on incinerator lower side walls. *In* Proceedings; 1968 National Incinerator Conference, New York, May 5–8, 1968. American Society of Mechanical Engineers. p. 136–141.

KAISER, E. R., C. D. ZEIT, and J. B. MCCAFFERY. Municipal incinerator refuse and residue. *In* Proceedings; 1968 National Incinerator Conference, New York, May 5–8, 1968. American Society of Mechanical Engineers. p. 142–153.

KAISER, E. R., and J. B. MCCAFFERY. Overfire air jets for incinerator smoke control. Presented at Annual Meeting, Air Pollution Control Association, New York, June 26, 1969. Paper 69–225.

KAISER, E. R. Incineration of packaging wastes with minimal air pollution. *In* Proceedings; First National Conference on Packaging Wastes, San Francisco, Sept. 22–24, 1969. Clemson, S.C., Clemson University. p. 181–190.

Criteria for Design and Control of Incinerators

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Grant No. EC 00330–01
Funds Awarded: $68,672
Project Period: June 1, 1969 to May 31, 1972

OBJECTIVES: Primarily to design a laboratory-scale experimental and theoretical program that will yield data pertinent to the control of conventional-design incinerators. Models utilizing combustion on grates useful for extrapolating existing data to new conditions and for optimizing incinerator design are being developed. Alternative schemes for burning refuse are also being evaluated.

APPROACH: A number of design and operating variables are being investigated in an attempt to find a variable that can be related to the quality of the residue and used to activate corrective action when the unburned fraction in the residue or in the stack gases becomes excessive. Included in these variables are excess air, fraction of air overfired, longitudinal distribution of air above and below the grate, air preheat, refuse bed height, and grate speed.

An experimental study of combustion is being made on a stationary fuel bed simulating a section of a traveling-grate stoker. Compositions and temperatures in and above the burning fuel bed, and infrared transmittance across the top of the bed are being measured in detail. Concurrently, a semiempirical mathematical model is being designed to extrapolate existing data to new conditions of operation or design so that operating conditions of the incinerator can be adjusted to accommodate changes in the quality of the refuse.

Findings: Efficient and clean incineration of refuse requires dynamic control responsive to the wide variations in the size and composition of the refuse. The theoretical and experimental programs in progress have been designed to provide a quantitative measure of the effect of random variations in the quality of the refuse. The computational model includes consideration of the drying, transient heating, pyrolysis, and residue burnout in addition to the complex interaction of the elements in a bed. The overbed reactions have been found to be controlled by mixing, and this suggests that considerable reduction in overbed volume should be achievable by more effective use of overfire jets. A laboratory-scale incinerator under construction, including continuous, detailed monitoring of bed height, gas composition, and temperature distribution, is being used to test the findings of the computations and to explore different methods of automatic control of incinerators.

Publications

Sarofim, A. F. Combustion reactions in overfire volumes. Presented to Grates and Combustion Committee, Incinerator Division, American Society of Mechanical Engineers, [New York], Jan. 15, 1970. (Unpublished manuscript.)

Fireside Metal Wastage in Municipal Incinerators

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Grant No. EC 00325–02
Funds Awarded: $257,859
Project Period: Mar. 1, 1969 to Feb. 29, 1972

Objectives: To identify the conditions leading to fireside metal wastage in solid waste incinerators, to determine the mechanisms by which metal loss occurs, and to devise corrective measures for this situation. Both field and laboratory studies are being conducted to provide data on the environmental conditions to which metal surfaces are exposed in incinerators and the effect of these conditions on metal wastage.

Approach: Flue gas temperature, composition and velocity, heat transfer rates, metal temperatures, dust loading, and composition of deposits on metal surfaces are being measured. This information is being related to the characteristics of the refuse being burned, the rate of incineration, the conditions of combustion, and the design of incinerators.

A special probe comprising specimens of several types of materials has been designed and inserted into an operating municipal incinerator. The probe was designed so that a combination of water and air cooling provides controlled temperatures. A thorough physical and chemical examination is being made on the metals and deposits after their removal from the incinerator.

The laboratory studies help define corrosion mechanisms and specific corrodents. Based on these studies, several means of alleviating metal wastage are being investigated. These include changes in construction materials and in furnace design, modification of combustion procedures, burning of supplementary fuels, and modification of solid waste fuel.

FINDINGS: The presence of lead, zinc, and chloride in specimens of boiler tube deposits is the most significant difference noted to date between the deposits from incinerators and those commonly encountered in coal- or oil-fired boilers.

Flue-gas samples taken in the New York incinerator over a period of 24 hr showed wide variations in the amount of corrosive gases present. The chloride concentration varied from 2.5 to 350 ppm, the fluoride from 0.27 to 3.3 ppm, and the sulfur dioxide from 0 to 100 ppm.

The most striking difference in the flue gas from an operating municipal incinerator in Ohio as compared with a power station was the presence of significant quantities of HC (up to 115 ppm), which probably results from the burning of certain types of plastic materials.

The first corrosion probe study was carried out for a period of 507 hr, including 312 hr at operating temperatures and 195 hr of shutdown. Significant corrosion was noted on the 34 individual specimens. For the most part the carbon steels exhibited general attack while the stainless steels showed some intergranular corrosion. The Type 304 stainless steel was the most corrosion resistant of the alloys evaluated.

Analyses of deposits built up on the corrosion probe during this 507-hr exposure period revealed a change in composition with probe temperature. As the average temperature of the probe increased from 350 to 1,250 F and higher, the concentrations of aluminum, silicon, magnesium, and calcium in the deposits increased. At the same time the concentrations of iron, lead, zinc, and potassium decreased. The sulfate concentration along the probe was found to be fairly uniform regardless of temperature while the chloride concentration was less at the higher temperatures.

Laboratory studies designed to provide controlled conditions for investigating corrosion of boiler tube materials by flue-gas mixtures and boiler deposit components have been conducted. Synthetic flue gases consisting of typical mixtures encountered in incinerators are being used with SO_2 and HCl to study corrosion of the same metals used in the probes. The metal specimens are in contact with compounds suspected of being the corrosive agents. Experiments to date have demonstrated that the corrosion by the flue gases alone is slight. When, however, the metal is in contact with a boiler deposit component such as lead chloride, corrosion is accelerated (lead and chloride have been found in boiler tube deposits). When the temperature is high enough to melt the lead chloride, the corrosion of the steels becomes severe.

Incineration of Plastics Found in Municipal Refuse

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Grant No. EC-00304-02
Funds Awarded: $187,350
Project Period: Mar. 1, 1969 to Feb. 29, 1972

OBJECTIVES: To study systematically the destruction of plastics and plastic-rich refuse by direct burning and by anaerobic heating followed by burning the volatile matter. Of particular interest are the chemical and toxicological nature of stack effluent and the interaction of the residue with water.

APPROACH: Various plastic materials commonly found in domestic solid waste, e.g., sheet goods, foams, castings, or paper-supported films, are being evaluated for combustion performance. Each material is tested for percentage moisture, volatile matter, fixed carbon and ash, and heat of combustion. The gaseous products of both combustion processes, direct burning and anaerobic degradation followed by combustion of the volatile components, are being analyzed and compared. If warranted, gas liquid chromatography, spectrophotometry, and other more definitive procedures are employed. Toxicity studies are made by exposing rats and plants to the gaseous effluent of the two combustion methods. In addition to percent reduction, the interaction of the various residues with water is being determined for reduction of BOD and for effect on water ecology.

Findings: The first year of the grant was devoted to building a flexible model incinerator, developing the necessary analytical procedures, and setting up equipment and procedures for the toxicity studies.

The model incinerator can be either batch fed or continuous; a wide variety of primary chamber and afterburner conditions is available. A movable probe in the afterburner permits GC analysis "on-line" to trace the destruction of the more refractory compounds.

The sample is continuously drawn into the stainless steel tip of the probe and cooled immediately to a predetermined temperature between the ice point and 200 C. The high-boiling fractions are immediately condensed in the tip of the probe. (These are later extracted and analyzed separately.) The remainder of the inducted gas is now available to a total-hydrocarbon detector and a concentrator. After a given period of time a concentrated sample can be fed either to the total-hydrocarbon detector, a thermocouple detector, or a GC column. Our greatest difficulty has been that gas mixtures have been too dilute for our apparatus. We have only recently rectified this with the adoption of a different concentration technique.

The gas that does not enter the probe is cooled to just above the dew point of its water. The fly ash is then collected and analyzed by size and composition.

Finally, the effluent is introduced to various plant and animal exposure chambers. By dilutions with clean, dry air, it is possible to subject these organisms to various humidity conditions and temperatures.

Fly and Economic Evaluation of Urban Garbage Systems

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Grant No. UI 00690—01
Funds Awarded: $45,879
Project Period: May 1, 1966 to Apr. 30, 1967

Objectives: To compare entomologic and economic evaluation of once-a-week garbage can service; twice-a-week garbage can service; once-a-week pickup from suspended paper bag containers; and twice-a-week service with paper bag containers.

Approach: Four economically comparable residental areas of approximately 500 homes each were studied in the city of Santa Clara, California, an area for each of the four systems. Paper bag containers were installed in two areas and use of standard garbage cans continued in the other two areas. Collection service was altered so that both once- and twice-a-week service could be compared between areas for each system. The new pickup schedules started about 1 month before the collection of data began so that residents and the collection company could become familiar with the new systems. Maggot traps were installed under 40 representative units in each area from which all migrating fly larvae were collected. Adult fly density was detected by using 20 standardized attraction stations in each of the four areas. The entomologic evaluation was determined from the combined adult and larval fly counts as they related to fly densities and fly problems during 8 weeks in August and September 1966.

The economic evaluation was primarily a time and motion study that compared the various aspects of the pickup service among the areas.

FINDINGS: The study indicated that the frequency of collection was probably more important than the type of system or container used, and although there was a reduction in fly numbers from once-a-week paper over once-a-week cans, the reduction was not enough to suggest adequate fly control. Both of the twice-a-week systems showed substantial reduction in fly production, but the twice-a-week can system would probably require considerable follow-up to achieve satisfactory control. Twice-a-week paper bags did achieve satisfactory fly control.

It was also found that as much as 30 percent savings in manpower could be achieved by substituting paper bags for metal cans but that unless the collection system was actually engineered around the paper bag concept the saving in time would probably not be sufficient to pay for the additional cost of the bags.

In conclusion, the following findings were made.

1. Once-a-week can containers produced excessive numbers of flies in about 67 percent of the containers, while 10 percent of twice-a-week cans produced significant numbers of green blow flies. The once-a-week paper containers produced flies in 20 to 25 percent of the containers while the twice-a-week paper containers had no containers with consistently high fly production.

2. Frequency of garbage service was an important control factor, since neither of the once-a-week systems achieved satisfactory control, whereas the twice-a-week systems did produce substantial control.

3. Individual garbage containers are independent fly sources with little or no dependence on nearby sources for their productivity.

4. Twice-a-week garbage service to suspended paper bag containers could achieve control of green blow flies provided that the community would be willing to bear the increased costs of the paper sacks and that 100 percent of the residences were included in the service.

PUBLICATIONS

ECKE, D. H., and D. D. LINSDALE. Fly and economic evaluation of urban refuse systems. I. Control of green blow flies (*Phaenicia*) by improved methods of residential refuse storage, and collection. *California Vector Views*, 14(4):19–27, Apr. 1967.

ROGERS, P. A., and G. L. BELLENGER. Fly and economic evaluation of urban refuse systems. II. An efficiency analysis of paper bag containers. *California Vector Views*, 14(5):30–37, May 1967.

Integrated Control of the Housefly

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Grant No. EC 00246–06
Funds Awarded: $77,203
Project Period: Sept. 1, 1963 to June 30, 1970

OBJECTIVES: To explore factors affecting the attractiveness of houseflies to various predaceous, manure-inhabiting mites and to study the susceptibility of these mites to insecticides commonly used for houseflies.

APPROACH: Two specific studies were conducted. In one study, mixed populations of manure mites were examined to determine if the combination of different species results in higher frequency of predation and phoresy.

Further work was carried out to isolate the pheromones present in manure and in houseflies responsible for the attraction of mites. Microsurgery techniques with a laser beam were used to investigate in greater detail the role of certain sensory areas in the mite for attraction.

In the other study, 16 compounds were laboratory tested to determine the comparative toxicities of various insecticides for housefly larvae and predaceous mites. Additional insecticides were screened for toxicity, and promising compounds underwent field evaluation.

Findings: An integrated fly control program, based on selective application of insecticides to the resting sites of the flies and encouragement of manure-inhabiting predaceous mite populations, has been developed for caged-poultry houses. This program reduces the amount of insecticide usage and cost.

The sensory structures of the housefly and a predaceous macrochelid mite have been determined and examined by electron microscopy. It is possible now to study the behavior of these insects in more detail and develop methods of increasing the predation rate and altering the habitat to reduce the survival of fly larvae.

Publications

Axtell, R. C. Phoretic relationship of some common manure-inhabiting Macrochelidae (Acarina: Mesostigmata) to the house fly. *Annals of the Entomological Society of America*, 57(5):584–587, Sept. 1964.

O'Donnell, A. E., and R. C. Axtell. Predation by *Fuscuropoda vegetans* (Acarina: Uropodidae) on the house fly (*Musca domestica*). *Annals of the Entomological Society of America*, 58(3):403–404, May 1965.

Farish, D. J. Some aspects of the sensory and phoretic behavior of *Macrocheles muscaedomesticae* (Scopoli, 1772) (Acarina: Macrochelidae) with a consideration of phoresy as a phenomenon. M.S. Thesis, North Carolina State University at Raleigh, 1965. 151 p.

Farish, D. J., and R. C. Axtell. Sensory functions of the palps and first tarsi of *Macrocheles muscaedomesticae* (Acarina: Macrochelidae), a predator of the house fly. *Annals of the Entomological Society of America*, 59(1): 165–170, Jan. 1966.

Axtell, R. C. Comparative toxicities of insecticides to house fly larvae and *Macrocheles muscaedomestica*, a mite predator of the house fly. *Journal of Economic Entomology*, 59(5):1128–1130, Oct. 1966.

Axtell, R. C. Integrated house fly control: Populations of fly larvae and predaceous mites, *Macrocheles muscaedomesticae*, in poultry manure after larvicide treatment. *Journal of Economic Entomology*, 61(1):245–249, Feb. 1968.

Willis, R. R., and R. C. Axtell. Mite predators of the house fly: A comparison of *Fuscuropoda vegetans* and *Macrocheles muscaedomesticae*. *Journal of Economic Entomology*, 61(6):1669–1674, Dec. 1968.

Axtell, R. C. Macrochelidae (Acarina: mesostigmata) as biological agents for synanthropic flies. *In* G. O. Evans, *ed.* Proceedings of the Second International Congress of Acarology, University of Nottingham, Sutton Bonington, England, July 19–25, 1967. Budapest, Akademiai Kiado, 1969. p. 401–416.

Farish, D. J., and R. C. Axtell. Phoresy redefined and examined in *Macrocheles muscaedomesticae* (Acarina: Macrochelidae). *Acarologia*. (In press.)

Axtell, R. C. Integrated fly-control program for caged-poultry houses. *Journal of Economic Entomology*, 63(2): 400–405, Apr. 1970.

Succession and Ecology of Diptera in Cattle Droppings

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Grant No. EC 00252–05
Funds Awarded: $77,326
Project Period: Oct. 1, 1963 to Sept. 30, 1970

Objectives: To study cattle droppings as ecologic units and to examine the extent to which the inhabitant organisms contribute to the breakdown and recycling of individual droppings.

Approach: The cowpat habitat is being studied, under both undisturbed pasture and experimental conditions, to determine the succession and density of various Diptera species that inhabit the droppings. The time, place, and pasture habitat in which individual cowpats are dropped are being assessed to determine how these factors affect surface succession and the subsequent fauna that develop in and emerge from such pats. Both naturally dropped and experimentally exposed pats of known sizes are being studied.

The interrelationships between fauna are being assessed by standardized sampling methods to determine the relationships among numbers and species of arthropods, the rate of cowpat degradation, the recycling of nutrients, and the effects of natural enemies on pests such as horn and face flies. Because the face fly, *Musca autumnalis,* is not yet present in California, another aim is to study the impact of an exotic species on the native fauna (or vice versa).

FINDINGS: The feces of larger animals, especially ruminant herbivores, are utilized as food and shelter by a large number of animal species, especially arthropods. There is a difference between the habitat of undisturbed cattle droppings as they lie in pastures and—as in a feederlot—that of cattle dung disturbed by man and heaped into manure piles or trampled by cattle in close confinement and mixed with urine. In California pastures, 109 different species of flies visited fresh cattle droppings, and at least 50 are known to have developed therein. By contrast, larvae of only seven fly species have been found in droppings in feederlots. The next largest order of arthropods collected in pastures was the Coleoptera, of which 35 species of beetles occurred in droppings in both the adult and larval stages. Most of the fauna of undisturbed cattle droppings also inhabit the feces of native wild herbivores such as bison and moose, but the pellet droppings of deer, elk, and wild and domesticated sheep are unsuitable for this fauna.

Publication of the first key to the families and major genera of flies that breed in undisturbed cattle droppings, including 18 families and 24 genera and annotations for most of the 50 species, filled a void. Since the faunae of undisturbed cowpats generally are widely distributed wherever there are cattle, the key and the accompanying description and discussion of these faunae serve as a basic guide to the insects associated with fresh, undisturbed cattle droppings in California and elsewhere in the United States.

In pasture situations, cattle feces are not likely to contribute to disposal or pollution problems, because of the role the indigenous arthropod faunae play in the biodynamics of individual droppings—the flies, beetles, and other inhabitants constitute important components of the pasture ecosystem because of the part they play in the breakdown and recycling of individual droppings. Most faunal members of the pasture community are beneficial and unobtrusive species; few persons even know they exist. The only pests associated with pasture feces are the obligate, host-specific parasites of cattle and bison—the horn fly, *H. irritans,* and the face fly, *M. autumnalis.* Only the face fly is an occasional pest of other animals (and sometimes of man when it is hibernating in houses).

Under range of pasture conditions, neither the house fly or the stable fly, *S. calcitrans,* oviposits or develops in the individual livestock droppings. On the other hand, house and stable fly larvae become the predominant species in droppings when cattle are confined in feederlots. When large numbers of cattle are confined in feederlots, horn and face fly populations are reduced to insignificant numbers because droppings are rarely left undisturbed, and almost all other "unobtrusive pasture flies" are excluded from this "unnatural habitat." In place of the two host-specific pest species mentioned, the feederlot frequently produces immense populations of house and stable flies. These two very noxious pests affect a wide range of animals and can and do affect man directly. The stable fly obtains blood from all types of domesticated mammals and is often a more serious pest of cattle than the horn fly. The feederlot is, then, a prime ecologic example of how catastrophic fluctuations in densities of certain insects (usually pest species) occur when man changes complex ecosystems into simple ones.

In pastures, the faunal composition on and within each fresh pat varies considerably; among other things, this depends upon when and where the pat is dropped. Pats dropped at night or on cold days form a crust before the usual early-stage inhabitants are active and are, therefore, excluded. Pats dropped in the shade may have distinctly different faunae than those in sunny locations, especially in hot weather. The factors determining the faunal composition of individual fresh pats derive from the fact that populations of different species are confined to various preferred local habitats or activity areas in a pasture. Each area has constantly shifting boundaries, and each species has different characteristic environmental requirements and powers of dispersal. In addition, the number of pats dropped in a specific locale at or near the same time and diurnal fluctuations in insect activity influence the numbers and kinds of insects that will eventually reach and colonize a fresh pat.

Each dropping is a discrete habitat unit, and the numbers of larvae of coprophagous and predaceous species of insects interacting with each other as they develop are determined by the number of larvae hatching from eggs laid by females on each dropping in the first few hours; after that, essentially no more prey or predators are introduced. Experimental studies reveal that larvae of the coprophilic Diptera have a remarkable ability to complete their growth from egg to pupa under a wide variety of physical conditions. Competition for food or space seems rarely, if ever, to be a mortality factor to larvae of the coprophagous species. In general, after the female lays her eggs in a dropping, the hatched larvae in an undisturbed dropping are quite certain of completing their growth to pupation unless killed by a predator or parasite. Other studies reveal that under natural field conditions, the mortality of coprophagous species of Diptera reared from droppings is correlated with the numbers of predators in each dropping.

The elimination of the normal faunae of individual cattle droppings in pastures by mechanical means or treatment with insecticides results in a prolonged period's being required for pat degradation and a consequent loss of usable acreage for grazing.

Publications

Anderson, J. R. Biological interrelationships between feces and flies. *In* Management of Farm Animal Wastes; Proceedings; National Symposium on Animal Waste Management, East Lansing, Michigan, May 5–7, 1966, Kellogg Center for Continuing Education, Michigan State University. ASAE Publication No. SP–0366. St. Joseph, Mich., American Society of Agricultural Engineers. p. 20–23.

Anderson, J. R. Recent developments in the control of some arthropods of public health and veterinary importance. Muscois flies. *Bulletin Entomological Society of America*, 12 (3):342, 1966.

Foster, W. A. Co-operation by male protection of ovipositing female in the Diptera. *Nature* (London), 214 (5092):1035–1036, June 3, 1967.

Poorbaugh, J. H., J. R. Anderson, and J. F. Burger. The insect inhabitants of undisturbed cattle droppings in Northern California. *California Vector Views*, 15(3): 1–36, Mar. 1968.

Anderson, J. R., and J. H. Poorbaugh. New livestock fly moves toward state. *California Agriculture*, 22(3):406, Mar. 1968.

Foster, W. A. Predatory behavior of *Scatophaga stercoraria* (Diptera: Anthomyiidae) in California. *Annals of the Entomological Society of America*, 63(1):338–339, Jan. 1970.

Dynamic Evaluation Procedure; Refuse-Handling System

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Grant No. UI 00513–02
Funds Awarded: $58,823
Project Period: Sept. 1, 1966 to Feb. 28, 1969

Objectives: To detail a descriptive simulation model of a solid waste management system in a cooperative study with the city of Atlanta, Georgia. To evaluate the effects of changes made in the system as a result of the study.

Approach: The perspective used in this study is called industrial dynamics (J. W. Forrester[1]), which grows out of four lines of earlier development: information feedback theory, automatized military tactical decision making, experimental design of complex systems by use of models, and digital computers for low-cost computation. This concept may be used to treat the interactions among the flows of information, money, orders, materials, personnel, and capital equipment in an industrial system.

This study used the solid wastes system of the city of Atlanta to collect data. Using this information, the research called for designing a model to portray systems behavior, providing a procedure for evaluating various proposals as potential system improvements from a standpoint of economy and efficiency, providing insight into the basic nature of the variables inherent in a solid waste system, and possibly disclosing new important variables.

Findings: Long-term control of solid waste pollution must be obtained by controlling the generating source of the problem—at manufacture.

Short-term waste treatment costs over a given period of time for a given level of problem seem to vary widely depending on the rate at which resources are spent to acquire the treatment capacity.

Considerable savings can probably be made on short-term treatment costs by focusing on the accumulations in the system. Application of the research grant findings was determined capable of reducing by 50 percent the annual operating costs of a major Florida city, if implemented.

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[1] Forrester, J. W. Industrial dynamics. Cambridge, M.I.T. Press, 1961. 464 p.

Mathematical Analysis of Solid Waste Collection

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Grant No. EC 00309–01
Funds Awarded: $15,190
Project Period: Mar. 1, 1969 to Feb. 28, 1970

Objectives: To determine optimal location of transfer stations and other facilities by use of a mathematical model, to investigate the effect of parameter changes on optimal policies, and to determine optimal routing of collection vehicles.

Approach: This research effort is an extension of the work done under research grant UI–00539–02 "Optimal Policies for Solid Waste Collection." An analytical model to determine the optimal location, type, and size of transfer stations was developed to minimize the overall cost of transportation and facilities. The values of the various empirical costs and coefficients included in the model were determined from data already gathered in the previously mentioned grant. Included were the cost of transportation as a function of collection frequency, crew size, vehicle type, household density, haul distance, and amortization policies.

Sensitivity analysis to show how the optimal location and cost are affected by changes of parameters was carried out for variables such as household density, frequency of collection, haul distance, crew size, type of vehicle used, pay scales, overtime pay constraints, land value constraints, equipment and facility amortization policy, and social and esthetic considerations.

Findings: A practical model for facility location has been developed and used to determine optimal locations. Investigation of sensitivity shows little change in results due to most parameter variations but a very great sensitivity to volume of waste generated.

A model for optimal vehicle routing has also been developed. This model is not practical for realistic routing problems.

Publications

REVELLE, C., D. MARKS, and J. C. LIEBMAN. An analysis of private and public sector location models. *Management Science*, 16(11):692–707, July 1970.

Mathematical Simulation of Refuse Collection and Disposal Systems

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Grant No. UI 00699–04
Funds Awarded: $75,067
Project Period: Sept. 1, 1962 to Sept. 30, 1967

OBJECTIVES: To develop a mathematical model to simulate municipal refuse collection and disposal practices. It will enable an engineer to predict the behavior of a wide variety of proposed designs quickly and accurately and thus to predict an optimum solution based upon more complex criteria than have been possible.

APPROACH: Data were first collected and analyzed in relation to costs of refuse collection and disposal unit operations and the expected type and amount of pollution resulting from these operations. From this, a comprehensive cost function for each of the operations involved was determined. Mathematical models were then formulated to describe current refuse collection and disposal practices. Variables incorporated into the collection system model included the physical characteristics of the refuse, storage facilities, frequency and type of pickup, capacity of the collection vehicles, collection time and labor costs, characteristics of the haul to the disposal site, and the overnight garage location of the collection vehicles. The use of transfer stations was considered as well as the use of more than one disposal operation. Variables included in the disposal operation model included the possibility of salvage operations, reclamation possibilities, direct cost factors, the contribution of the disposal practices to air and water pollution and to reduction in land values, and benefits derived from reclaimed land.

FINDINGS: Part 1 of this research began with consideration of problems, called "location-allocation" problems, in which several disposal sites were physically located with simultaneous allocation of refuse sources to disposal sites. The disposal sites were located anywhere in a plane, and the measure of effectiveness was minimization of aggregate haul distance. By measuring distance with the e_1-metric three things were accomplished, as follows.

1. It was possible to reduce these e_1-metric location-allocation problems to mixed-integer programming problems.
2. Using the mixed-integer programming formulation, one may add constraints that prescribe certain areas for the placement of disposal sites.
3. The single-site location problem has a closed-form solution related to the geometric median of the source points. By using this property, a Theory of Median Sets was established and an alternating location-allocation algorithm was constructed for the multisite problem.

A second class of problems called "selection-allocation" problems was defined. Here the set of eligible disposal site locations was known, and one picked a proper subset of these and a refuse source allocation that minimized the aggregate haul distance or cost. These problems were characterized as mixed-integer programming problems with a coupled network analog and an approximating algorithm, and the Minimum Elimination Gain

Algorithm was established. This algorithm was extended to consider weighted sources and site acquisition costs. The network analog was extended to consider site acquisition, facility development, and operation costs as well as aggregate haul cost.

Part 2 of this research traced the development of two computer simulation models. The first model was based on the daily route method of refuse collection practiced in the village of Winnetka, Illinois. With data relevant to Winnetka, a series of simulation runs was made to delineate the interdependencies of parameters involved in the functioning of a refuse collection system. In particular, the percent of truck capacity used, the number of daily trips, the overall collection efficiency, the length of workday, the haul efficiency, and the haul time as a percentage of total time were measured as functions of the coefficient of variability of refuse production, the refuse assignment, and one-way haul distance. A further set of runs studied the effect of the number of unloading platforms on average and maximum waiting times at the disposal site. The interpretation of the results presented in tables and graphs allowed numerical bounds on the usefulness of the daily route method to be established regarding the coefficient of variability, the refuse assignment, and haul distance.

The second model was based on constant-length workday rules found in Chicago, Illinois. With data relevant to Chicago, a series of runs was made to measure the quality of service and cost effectiveness of different combinations of overtime, last-load relay, and assignment policy. Here assignment means both the average daily number of truckloads and the average daily number of 8-hour shifts. The results presented in a series of tables show as one example that the use of overtime is most cost effective when combined with a reasonable time assignment.

PUBLICATIONS

QUON, J. E., A. CHARNES, and S. J. WERSAN. Simulation and analyses of a refuse collection system. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 91 (SA5):17–36, Oct. 1965.

QUON, J. E., M. TANAKA, and A. CHARNES. Refuse quantities and frequency of service. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 94 (SA2):403–420. Apr. 1968.

CHARNES, A., and W. M. RAIKE. One-pass algorithms for some generalized network problems. *Operations Research*, 14 (5):914–924. Sept.–Oct. 1966.

CHARNES, A., and K. KORTANEK. A note on the discrete maximum principle and distribution problems. *Journal of Mathematics and Physics*, 45 (1):121–126. Mar. 1966.

QUON, J. E., M. TANAKA, and S. J. WERSAN. Simulation model of refuse collection policies. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 95 (SA3):575–592. June 1969.

Optimal Policies for Solid Waste Collection

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Grant No. UI 00539–01
Funds Awarded: $56,018
Project Period: Jan. 1, 1967 to Dec. 31, 1968

OBJECTIVES: To study the feasibility and economics of establishing transfer points in waste collection systems of large cities. To devise, through a computer-oriented systems analysis study, more efficient use of manpower and equipment.

APPROACH: This study developed information concerning the characteristics of optimal policies for use in urban decisions by engineers and municipal decision and policy makers. A mathematical model based on data available from the city of Baltimore was simulated to investigate the location and spacing of transfer stations. Problems such as crew size, frequency of collection, vehicle routing, and type of equipment were analyzed.

The study prepared and programmed three

mathematical models of FORTRAN IV for use in digital computers. The models simulated the operations of solid waste collection systems in urban residential areas using compactor trucks. Proposed policy changes in a system can be evaluated by use of the model rather than by changes in actual field operations.

The system variables that can be controlled in some or all of the models are the following: density of households per acre, haul distances from neighborhoods to disposal site, truck crew, crew size, collection frequency, pay scales, overtime policy, amortization policy, season, use or nonuse of a transfer station, size of transfer station trailers, use or nonuse of transfer station compaction apparatus, haul distances from transfer stations to disposal site, and use or nonuse of queues at transfer stations.

The relative efficiencies of the systems being compared were measured in dollars-per-ton-costs. Costs of residential triweekly collection versus biweekly collection were compared. For a particular urban tract with the controllable variables defined, the model generated the number of collection trucks by number and by days to areas within the tract.

The combinations of variables that make the use of a transfer station economically desirable were investigated.

FINDINGS: The final model (Model III) is suitable for use by any city in investigating system changes.

For the area of Baltimore investigated, the break-even haul distance for a transfer station is about 8 miles. Auxiliary compaction is a marginal operation. Increasing collection frequency from two to three per week results in a 10 to 15 percent cost increase.

PUBLICATIONS

TRUITT, M. M., J. C. LIEBMAN, and C. W. KRUSE. Simulation model of urban refuse collection. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 95(SA2):289–298, Apr. 1969.

The Physical and Chemical Composition of Municipal Refuse

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Grant No. EF 00146–05
Funds Awarded: $84,165
Project Period: Sept. 1, 1957 to Dec. 31, 1962

OBJECTIVES: To develop physical and chemical methods of sampling and analyzing municipal refuse. To determine the amount of solid waste generated and its characteristics.

APPROACH: Field studies were conducted in seven major Midwestern cities to obtain samples of refuse for laboratory analysis and to determine the amounts generated from different socioeconomic neighborhoods. The sampling methodology was evaluated.

Laboratory studies were conducted to determine the error due to two necessary sampling stages of the collected refuse before chemical analyses. Laboratory studies included the development of reliable methods of determining the following tests on municipal refuse: moisture, lipids, carbon, nitrogen, K_2O, P_2O_5, sulfur, and calorific value.

FINDINGS: The determination of the parameters of lb per capita per day, lb per household per day, cu ft per capita per day, and bulk density for a "homogeneous" residential area within a community required a sample of approximately 175 households for obtaining accuracies within 10 percent of the mean from the mean at a confidence level of 95 percent.

On the basis of more than 2,400 samples obtained from Milwaukee, Wisconsin; Toledo, Ohio; and Bloomington and Indianapolis, Indiana, it was determined that significant differences exist in the quantity and quality of the refuse produced in high, medium, and low socioeconomic sections of the cities.

On the basis of more than 65 separate studies in these four cities, the following logarithmic relationship was found between the sampling ratio (population of sample areas divided by total city population) used and the percent sampling error (percent error between extrapolation of sample data to estimate total city production and actual total city production):

$$Y = O.122\ e^{-0.781\ X}$$

where Y = sampling ratio, expressed as a decimal

X = percent sampling error

e = base of natural logarithm

NOTE: It is recommended that at least 400 people be used as a total sample population when a refuse sampling study is conducted.

The following procedure for processing samples of refuse before laboratory analysis is recommended:

> Shred combustible portion of the refuse with a forage harvester to a maximum size of 2 to 3 in. Select a "representative" sample of from 1,000 to 3,000 g and determine the moisture content by drying in a forced-air oven at 70 C. Grind dried material in a standard laboratory-type Wiley Mill to a maximum size of 2 mm. Store in an airtight, labeled can until needed for subsequent chemical analysis.

This sampling step, plus the sampling of the material in the airtight can for as little as 2 g in some cases, was found to have the following overall sampling error:

1. One has 95 percent confidence that, if only one sample is selected from the initially shredded *paper* material, and this sample is, in turn, subsampled after drying and grinding to obtain a final aliquot for a chemical determination, the overall sampling error will not exceed 10.3 percent.

2. One has 95 percent confidence that, if only one sample is selected from the initially shredded *garbage* material, and this is, in turn, subsampled after drying and grinding to obtain a final aliquot for a chemical determination, the overall sampling error will not exceed 7.2 percent.

Recommended methods of chemical analyses for the combustible portion of refuse were developed during the project for moisture, volatile solids, ash, lipids, liquid content, sulfur, nitrogen, carbon, hydrogen, C/N, P_2O_5, K_2O, and calorific value.

The following "empirical factors" were developed for the determination of carbon and hydrogen of garbage, remaining combustibles, and total combustibles of a refuse:

Raw garbage: $\%\ C = (100 - \%\ \text{Ash})/1.97$
$\%\ H = (100 - \%\ \text{Ash})/12.8$
Remaining combustibles: $\%\ C = (100 - \%\ \text{Ash})/2.18$
$\%\ H = (100 - \%\ \text{Ash})/14.7$
Total combustibles: $\%\ C = (100 - \%\ \text{Ash})/2.08$
$\%\ H = (100 - \%\ \text{Ash})/14.4$

A special study in Indianapolis, Indiana, where the people do a great deal of backyard incineration, showed the following findings.

1. If the people *were asked* to put out all their refuse, an increase from 3.4 to 8.3 million lb and from 4.0 to 5.2 million lb of refuse per week could be expected in December and August, respectively.

2. If the people *were required,* by ordinance, to put out all their refuse, an increase from 3.4 to 10.6 and from 4.0 to 7.4 million lb of refuse per week could be expected in December and August, respectively.

The results of a questionnaire in the 119 cities having a population of more than 100,000 in the United States (1958) indicated that:

1. Only 3.3 percent of 95 of the larger cities in the United States conduct refuse-sampling procedures on a routine basis.

2. Only 19 percent of 95 of the larger cities in the United States have their own laboratory facilities for determining either ash content or moisture content.

3. Only 9.5 percent of 95 of the larger cities in the United States have their own laboratory facilities for refuse grinding or determination of calorific value.

PUBLICATIONS

BELL, J. M. The physical and chemical composition of municipal refuse. *The APWA Reporter*, 29(1):11, Jan. 1962.

ETZEL, J. E., and J. M. BELL. Methods of sampling and analyzing refuse. *The APWA Reporter*, 29(11):2–4, 18–21, Nov. 1962.

BELL, J. M. Characteristics of municipal refuse. *In* Proceedings, National Conference of Solid Waste Research, Chicago, Dec. 1963, University of Chicago Center for Continuing Education. Special Report No. 29. American Public Works Association, 1964. p. 28.

Comprehensive Studies of Solid Waste Management

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Grant No. EC 00260–04
Funds Awarded: $792,822
Project Period: June 1, 1966 to May 31, 1970

OBJECTIVES: To develop an overall system by which the economic, administrative, planning, land use, logistic, technologic, engineering, health, and waste-generating aspects of the solid waste problem of a community or region can be evaluated in designing a waste management scheme for that area.

APPROACH: A number of research teams investigated the various aspects of solid waste management, including operations research, planning and economics, public health, and technology.

The operations research team developed an overall solid wastes generation and evaluation model. This model included constituent submodels that interrelated land use, technologic, economic, population, transport, and all other aspects of solid waste management. The time horizon for the overall model was 20 to 50 years. The planning and economics team related land use to the nature and volume of refuse materials to be handled, with major emphasis on the ultimate disposal of wastes. The public health team evaluated the relationship between solid waste management procedures and health dangers to the public and advised the other research teams on the possible public health implications of their alternate proposals for waste management.

The research teams concerned with technology, investigated many processes, including anaerobic digestion and sludge processing, and pyrolysis—combustion, wet oxidation, and biological fractionation. The underlying principle of the anaerobic digestion and sludge-processing scheme was the assumption that various organic fractions of solid waste can conceivably be transported to a sewage treatment plant either via water carriage or by trucks. If this mixed organic matter could be digested anaerobically, it would be reduced in volume and at the same time conditioned so as to minimize its insult to receiving land. A pilot plant was built to digest anaerobically a solid waste-sewage sludge mixture, and the operational parameters developed in laboratory studies were refined. The pyrolysis-combustion process is one in which organic matter is converted to combustible gases, and the gases are, in turn, burned to produce heat. Pilot-plant studies developed techniques for using various types of wastes as a fuel for the pyrolysis-combustion process. The pyrolytic gases produced were used for sustaining the process and as a source of energy to be recycled to the industry and community producing the wastes. Laboratory and pilot-scale research investigated the possibility of using a wet-oxidation process to convert all but the most exotic synthetic organic compounds to simple oxidation products having industrial value. Organic chemical yields were determined and the various chemicals produced were identified. Biological fractionation studies centered around the enzymatic hydrolysis of the cellulosic portion of solid waste to form glucose. Laboratory and pilot-scale investigations were made to optimize the glucose production.

Findings: In the first stages of the research an overall waste management model was developed in which the final output was a "waste collection, treatment, and disposal" component. Components of the model serving as inputs to the final component were "regional economic," "waste generator," "interregional analysis," "national economic," "population," "process technology," "spatial distribution of wastes," "land use," and "public health." The framework of the model having been established, the subsequent efforts were devoted to collecting data and formulating inputs for the various components of the model. Major progress was made in establishing the waste generator, spatial distribution of wastes, land use, process technology, and public health models.

Public health. By means of five extensive tables, data on the types and composition of solid wastes and the fate of the components of their breakdown products were screened and evaluated; as a result of this activity, the fractions of the solid waste stream that might have public health significance were identified. The public health significance and environmental fate of the various fractions in relation to wastes processing or disposal were evaluated. Means were suggested for keeping those components shown to constitute a significant hazard from entering the environment in such a manner as to come in contact with man. One of the major conclusions of the public health aspects of the research was that at present there is more need for research teams on which public health specialists are prominent contributors along with scientists and technologists than for specific health-oriented studies.

Planning and economics. The planning and economics study led to the development of the concept of functional boundaries and to the formulation of waste multipliers based on type of economic and demographic activity. In line with this approach, it was found that the traditional 4 to 6 lb/capita waste figure was far below the amount of wastes actually generated. The research team showed that the amount of solid wastes handled at landfill disposal sites was only about 50 percent of the total solid wastes production. This finding was confirmed later by studies conducted by the California State Department of Health. The work was later expanded to include a study of related aspects of the solid wastes management problem, such as the questions of local versus regional solution, alternate pricing systems, and development of efficiency versus equity criteria. During the research, network flow models were developed for the efficient rerouting of solid wastes from origin to sites; an economic survey was made of engineering aspects of current and experimental technologies' disposal costs.

Operations research. The operations research group developed a solid waste regional forecasting model in which the 28 sectors in the 9-county San Francisco Bay region were recognized. One of the novel features of the model is its ability to forecast waste generation for large communities. The procedure used in developing the model was based on the Leontief input-output model.

This portion of the study was concerned with the development of a model showing optimal service policies for solid waste treatment facilities. In the approximate version of the problem, the cost structure was described by a quadratic processing cost rate charged at the end of each period, and a linear holding cost charged at the end of each period. The arrival stream was considered to be periodically interrupted and divided into alternating "on" and "off" intervals of fixed length. The distribution of the cumulative quantity of waste that arrives during each "on" interval was represented by its first two moments. No wastes were assumed to come into the processing facility during each "off" period. The optimal service rates were found to be linear in the waste level at the start of each "on" interval and piecewise linear in the quantity of waste present at the start of each "off" period.

Anaerobic digestion. In accordance with the exploratory nature of objectives of the anaerobic digestion studies, experiments were concerned with the effect on the digestion process of adding the various ingredients of typical refuse to the input to the digester. Thus, it was found that once a digester culture is adapted to using green garbage as a substrate, it can digest the garbage as efficiently as it does raw sewage sludge, and at about 90 percent of the gas production from sludge digestion. More than 90 percent of the cellulose added as Kraft paper was digested. Newspaper (as found in domestic wastes) was only about one-half as digestible as Kraft or raw sewage sludge. Garden debris was digested at a rate and extent equivalent to those of garbage or sludge but with a gas production equal to only 75 percent of the latter. Wood was virtually unchanged in the digestion process. A composite of all the ingredients of domestic refuse was digested at solids destruction efficiency of about 65 percent. Gas production was about 63 percent of that obtained from digesting an equal amount of sewage sludge. During the study, a kinetic model of the anaerobic biologic hydrolysis of cellulose was developed by one of the researchers as a part of his work on a doctoral dissertation. An economic analysis showed that the total costs (1960 dollars) for digesting municipal refuse would be about $2.18/ton for a city of 300,000, and 0.78/ton for a city of 1 million.

Wet oxidation. A wet-oxidation unit capable of treating 40 liters of slurry on a "batch" basis or of being operated on a continuous basis was constructed and used in preliminary experiments. In these experiments, the reaction temperature was varied from 160 to 220 C in 20-degree increments, and air was applied at 1 to 2 cu ft/min. Air (partial) pressure was raised to 180 psia. Under these conditions maximum dissolved solids yield (i.e., maximum total organic chemical yield) was about 35 percent of the total solids input. Residual solids yields decreased to some extent and volatized carbon yields increased with temperature increase; dissolved solids yields increased with temperature until a maximum was reached, after which they began to decline. Residual solids and volatilized carbon yields were smaller and dissolved solids yield was greater for every 2 cu ft of air per minute at every reaction temperature. The cellulosic fraction of wood is preferentially attacked under acidic conditions. Organic chemicals produced in the reactions were those from oxidative degradation of the component pentose and lexose manomers of wood, e.g., acetic, formic, lactic, glycolic, and other acids.

Pyrolysis combustion. Work in the pyrolysis-combustion studies was concerned mostly with the design and construction of a reactor capable of handling 200 lb of refuse per hour. The design of the reactor departs from the usual pyrolysis reactor in that a limited amount of combustion is provided to bring the temperature of the pyrolysis-produced gases to 800 to 1,200 C. These gases are used to bring the wall temperature of the pyrolysis chamber to 800 to 1,200 C. The operation of the unit is sufficiently flexible to permit the production of useful intermediate breakdown products or to carry the destruction process to a point at which only CO_2, H_2O, and inert ash need be discharged to the environment.

Biofractionation. The work done on biofractionation led to the development of a fermentation geared to the optimum conditions for the biological hydrolysis of cellulose to glucose and the culture of a potential feedstuff on the glucose. A number of organisms were surveyed. The one found most suited to the process was the fungus *Trichoderma viride.*

General. During the research period, the pertinent literature was extensively covered—more than 700 publications were reviewed and abstracted. This activity led to the publication of two highly useful reports. A third is being compiled. When it is finished, the number of publications thus reviewed will number more than 1,000.

PUBLICATIONS

GOLUEKE, C. G., and P. H. MCGAUHEY. Future alternatives to incineration and their air pollution potential. *In* Proceedings; Third National Conference on Air Pollution, Washington, D.C., Dec. 12–14, 1966, National Center for Air Pollution Control, Public Health Service, U.S. Government Printing Office, 1967. p. 296.

MCGAUHEY, P. H. Living with our wastes. *In* J. E. Flack, and M. C. Shipley, *eds.* Proceedings; Ninth Western Resources Conference, Man and the Quality of His Environment, University of Colorado, Boulder. July 5, 1967. University of Colorado Press, 1968

GOLUEKE, C. G. Comprehensive studies on waste management. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, University School, Milwaukee, July 24–28, 1967. Conference Preprint No. A–1. 3 p.

Golueke, C. G., and P. H. McGauhey. Comprehensive studies of solid waste management; first and second annual reports. Public Health Service Publication No. 2039. Washington, U.S. Government Printing Office, 1970. 245 p.

Golueke, C. G. Solid waste management: abstracts and excerpts from the literature. v. 1 and 2. Public Health Service Publication No. 2038. Washington, U.S. Government Printing Office, 1970. 147 p.

Anderson, L. E. Comprehensive studies of solid wastes management; a mathematical model for the optimization of a wastes management system. Rev. by A. K. Nigam. SERL Report No. 68–1. Berkeley, University of California, Feb. 1968. 63 p.

Stern, H. I. Comprehensive studies of solid wastes management; optimal service policies for solid waste treatment facilities. SERL Report No. 69–6. Berkeley, University of California, May 1969. [139 p.]

Golueke, C. G. Chemical and microbial characteristics of urban solid wastes. [Presented at Annual Meeting, American Society for Microbiology, Miami Beach, May 4–9, 1969.] 17 p.

Brink, D. L., P. K. Basu, and J. F. Thomas. Pyrolysis—combustion: a new type of recovery system. Unpublished data, Department of Forestry and Conservation, University of California, Berkeley, 1970.

Decision Making and Solid Waste Disposal

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Grant No. EC 00281–02
Funds Awarded: $201,008
Project Period: Mar. 1, 1969 to Feb. 28, 1971

Objectives: To measure the influences of economics in solid waste disposal and to formulate methods of using economic analysis as a guide in designing facilities, including attention to costs of alternative technologies. To identify the factors initiating, supporting, opposing, and negotiating refuse disposal decisions and to classify and analyze areas of interaction. To determine the nature and extent of short-run opinion changes by local people and to develop education approaches that may be desirable to decrease aversions to location of facilities.

Approach: Various solid waste management methods, i.e., landfills, incineration, composting, and so forth, are being compared to determine conditions under which different cities may find cost advantages in particular technologies. An attempt is being made to understand cost variations and to separate out the extent to which these are due to differences in land and labor costs, differences in techniques of disposal used, and differences in efficiency. The efficiency of private companies and of public agencies is being compared. The effect of existing regulations on private waste disposal is being evaluated. Hypotheses are being formulated and investigated about policy approaches involving regulation, financing, pricing, and other measures aimed at ensuring arrangements that will be conducive to waste disposal procedures permitting maximum attainment of goals.

A decision-making framework was formulated from empirical data and theoretical concepts. Selected decisions about the location of solid waste disposal sites were analyzed to provide basic empirical data. Physical and social factors, including those often termed political, were considered. Eighteen requests for permission to operate sites for the disposal of solid wastes were analyzed. Of the 18 cases, 5 are instances of rail haul while the others involve truck transfer to sanitary landfills. The significant factors were identified and related to the socioeconomic situations of the community in which the decisions were made.

At the same time, two rail haul proposals were analyzed with an emphasis on understanding the social psychologic factors that affect protest. Ethnographic information and personality factors leading to certain attitudes, attitude changes, and willingness to act are being investigated.

Findings: Much progress has been made in the development of an economic framework for analyzing solid waste disposal consistent with a constructive use of resources instead of a negative destruction and riddance approach. Major components of the economics of solid wastes as a field of inquiry have been identified, including classification of various waste disposal activities and delineation of subjects of inquiry ranging from elementary cost comparisons, to more sophisticated comparisons, to the analysis of solid waste disposal systems, to the economic evaluation of institutional arrangements, and to legal and policy areas. For all but the legal and policy areas, substantial progress has been made in developing conceptual frameworks to guide our own and other people's efforts. This work is being continued. Also being continued is the empirical work on demand for disposing of wastes; on the analysis of cost function, including design of needed data collection systems; and on the evaluation of entire waste disposal systems.

An important factor in planning future solid waste management is the volume of refuse expected to accrue in later periods, as well as its composition. To obtain estimates of future solid waste figures, one could simply extrapolate the trend observed in the past. One might, however, be caught by surprise when so doing, since new trends become predominant that were not apparent in global figures but that would have been detected by a more careful analysis of the data.

For a statistical cost analysis of solid waste disposal, multiple regressions were based on National Survey data. Although this approach was successful in depicting cost functions for municipal incinerators, it did not do very well for small incinerators and landfills. This is probably due to data deficiencies, and one main conclusion from our work so far is that a major effort must be undertaken to collect better data. In view of this, normative cost accounting sheets have been developed. If adopted by managerial personnel, they would ensure that cost items would be reported in a standardized way to yield meaningful cost information. These are prerequisite for a rigorous economic analysis as needed for planning future solid waste management.

From the site proposals studied a number of important factors were found. By constructing a series of matrices, factors such as visibility of a site, lower status of the community involved, the mayoral form of government, and reclamation were found to be positively related to acceptance of sites. Factors such as a perceptible reclamation, site size, and distance from a site to the nearest residence were found to involve some important qualifications. Reclamation was found to be positively related to acceptance of a site but apparently had little effect on whether or not significant protest took place. Size of a site and its duration were not found to be positively related to acceptance of a site. Factors such as distances were found to vary considerably. A community typology consisting of four types was developed.

Type I—incorporated area for a single community—three proposals—all successful

Type II—outside the region for a single community—five proposals—all unsuccessful

Type III—incorporated area for multiple communities—one proposal—successful

Type IV—within the region for multiple communities—nine proposals—six successful, three unsuccessful

If one considers the eight communities with urban settings and middle to high status, protest was significant after the public hearing in only three, and seven of the eight proposals were ultimately implemented. In the remaining seven communities with lower status or with rural or isolated settings, only three of the proposals succeeded and all were protested. But protest is most effective in cases of the Type II variety where a single community transports its refuse outside the region. Although there is a tendency to go toward the areas where there is a great deal of open space with as few residents as possible, perhaps more is lost in this strategy than gained. Because of the township system there is no area in which the local community gives up its jurisdiction except for those without zoning and zoning ordinances. As was very clear in the rural or isolated communities studied thus far, the proportion of citizens protesting in these areas was vastly more significant than in urban areas. In fact, their absolute number was almost always higher. Not only did such communities see themselves as highly self-sufficient with regard to disposal, but also some economic changes that were likely to occur there would be significantly different than they might have been elsewhere.

In Denver, San Francisco, and possibly in Milwaukee, rail haul does not appear to be able to compete with systems incorporating truck transfer. Intergovernmental arrangements are indicated as having added to the planning problems—it is difficult to get all necessary contracts in line in a metropolitan area. Finally, the specific problems of rail haul parallel the general problem of misinformation that has characterized solid waste disposal efforts. For example, Philadelphia was cited in the San Francisco proposal as evidence of the success of the rail haul concept. Its concept has not yet, however, gone into operation. Another example of misinformation is that the published cost estimates of rail haul systems indicate that some are going to reap unbelievably large profits or that others are going to sustain colossal losses.

In the social psychology work, personality factors leading to certain attitudes, attitude changes, and willingness to act were investigated. Sex differences were observed; women changed more often and to a greater extent than males. In addition, a number of factors such as trust in public officials, trust in the private operators, and previous community changes were identified as important in the decision. Other factors such as distrust toward outside agents were also found to be important. Among those who are more fearful and apprehensive and who tend to avoid risks (the harm-avoidance scale), those who favored the proposal *before* the discussion were more willing to act than those who opposed it, while those who favored the proposal after the discussion were *less* willing to act than those who opposed it. In other words, the propensity to take risks was associated with willingness to act if one was negative to the landfill before the discussion and if one was positive to the landfill after the discussion. This suggests either that individuals who were originally riskier and more willing to act shifted from a negative to a positive attitude or that the discussion made the risks involved in the landfill more salient and thus increased the negative relation between willingness to act in favor of the landfill and harm avoidance and the amount of attitude change, whether positive or negative. These findings are not satisfactorily explained, but they do suggest that distinctive appeals will be successful in motivating opposing groups in a landfill controversy.

PUBLICATIONS

HAVLICEK, J., JR., G. S. TOLLEY, and Y. WANG. "Solid wastes"—a resource? *American Journal of Agricultural Economics*, 51(5):1598–1602, Dec. 1969.

Standard Test Procedures for Municipal Solid Wastes

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Grant No. EC 00332–01
Funds Awarded: $38,887
Project Period: June 1, 1969 to May 31, 1972

OBJECTIVES: To develop standard test procedures for the physical, chemical, and biological characterization of municipal solid wastes. This information will implement better design, operation, and environmental control of the collection, storage, transport, processing, and disposal of municipal solid wastes.

APPROACH: Presently used test procedures for the examination of municipal solid wastes, as well as recommendations for other desired analysis, are being investigated by means of a questionnaire survey sent to people and agencies involved in solid waste management. An Advisory Committee on Test Procedures for

Municipal Solid Wastes is being formed from representatives of the agencies surveyed and through technical associations and societies. This committee would provide the broad base for direction in standardization of test procedures and dissemination of information through the constituent societies. Personal contact and an extensive literature search are also being made.

These existing procedures will be evaluated through consultation with the agencies and actual performance of the test for accuracy, precision, reproducibility, and appropriateness. Sampling procedures and sample preparation are also being investigated so that the representativeness of samples taken from extremely heterogeneous municipal solid waste can be ascertained.

As a result of this work, shortcomings of existing methods and recommendations for improving them can be delineated.

FINDINGS: A survey of the State's solid waste planning directors indicated that their activities have been confined to solid waste planning and quantitative data gathering. Very little qualitative analysis is being performed. The need for a set of standard test procedures for solid waste analysis was, however, recognized and encouraged. A literature review indicates that test procedures for the examination of refuse have been borrowed from *Standard Methods for the Examination of Water and Wastewater*, ASTM, and AOAC. Researchers at several universities have developed or revised existing analysis procedures to meet project objectives, the most extensive work being in the area of incinerator residue characterization at Drexel University, Harvard University, and New York University. The BSWM intramural forces have done extensive work in the area of sampling and sample preparation as well as in the development of specific analytical procedures. These methods are being compiled for evaluation.

Biologic Consequences of Plant Residue Decomposition in Soil

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Grant No. EC 00267–06
Funds Awarded: $211,779
Project Period: Feb. 1, 1964 to Mar. 31, 1971

OBJECTIVES: To investigate and determine the nature and action of phytotoxic substances released into soils during plant residue degradation. To assess the biologic consequences arising from the decomposition products on succeeding crops and their diseases. To ascertain the relationships between decomposition products and types of plants and environmental factors. To evaluate the role of degradation products in the survival of pathogens in soil and to determine the nutritional requirements for pathogenicity and the role of crop residues in providing such nutrients.

APPROACH: The plant organic-residue sources are barley, rye, soybean, timothy, and other common plants—all of which are known phytotoxin producers upon decomposition. Phytotoxins are obtained by extractive procedures, and isolation and identification are attempted by use of chromotographic and chemical techniques. Phytotoxicity assays are run at the analytical separation stages by evaluation of seed germination and root elongation. After identification, plant evaluation studies are made in nutrient culture and nonsterile soil growth conditions. The persistence and prevalence are determined for the identical compounds in nature. *Fusarium* and *Thielaviopsis* organisms are used to determine the effect of phytotoxins on their parasitic activity in laboratory and whole-plant greenhouse studies. Soybean and barley tissue at various stages of decomposition in natural soil under controlled conditions is assayed for the appearance and duration of production of these compounds.

Findings: Bioassays, using lettuce and tobacco seed germination and root-elongation, demonstrated the phytotoxicity of water extracts of barley, rye, broccoli, and vetch residues decomposing in the field. Four phenyl acids were identified that accounted for much (50 to 60 percent) of the phytotoxicity of the extracts.

In the laboratory studies these phytoxins were shown to predispose hosts to *Thielaviopsis* root rot. During the work with *Thielaviopsis* the process of chlamydospore germination was demonstrated. Residue-related damage to lettuce seedlings in fields in the Salinas Valley was not correlated with the phytotoxicity of extracts from decomposing residues in these fields. Field and greenhouse studies showed that incorporation of barley, rye, or broccoli residues into field soils consistently increased the population density of *Pythium ultimum*. In the first 3 to 4 weeks following residue incorporation the increased population of *Pythium ultimum* caused significantly more damping off and root injury to lettuce seedlings. Subsequently, even though the *P. ultimum* population remained greater in residue-amended soils, the degree of damage to lettuce seedlings was less than that observed in nonamended soils. The residue-related damage observed in the field was due to the effect of the residue on pathogen populations, particularly its utilization as a substrate by *P. ultimum*.

Publications

Patrick, Z. A., T. A. Toussoun, and L. W. Koch. Effect of crop-residue decomposition products on plant roots. *In* Annual Review of phytopathology. v. 2. Palo Alto, Calif., Annual Reviews, Inc., 1964. p. 267.

Patrick, Z. A., T. A. Toussoun, and H. J. Thorpe. Germination of chlamydospores of *Thielaviopsis basicola*. *Phytopathology*, 55(4):466–467, Apr. 1965.

Patrick, Z. A., R. M. Sayre, and H. J. Thorpe. Nematocidal substances selective for plant-parasitic nematodes in extracts of decomposing rye. *Phytopathology*, 55 (6): 702–704, June 1965.

Sayre, R. M., and Z. A. Patrick. Selective toxicity of some volatile fatty acids to plant-parasitic nematodes. *Phytopathology*, 55(10):1074, Oct. 1965. (Abstract.)

Linderman, R. G., and T. A. Toussoun. Behavior of chlamydospores and endoconidia of *Thielaviopsis basicola* in nonsterilized soil. *Phytopathology*, 57(7):729, July 1967.

Linderman, R. G., and T. A. Toussoun. Pathogenesis of *Thielaviopsis basicola*. *Phytopathology*, 57 (10):1007, Oct. 1967. (Abstract.)

Linderman, R. G., and T. A. Toussoun. Predisposition to Thielaviopsis root rot by phytotoxins obtained from decomposing plant residues. *Phytopathology*, 57 (8):819, Aug. 1967. (Abstract.)

Toussoun, T. A., A. R. Weinhold, R. G. Linderman, and Z. A. Patrick. Identification of phytotoxins obtained from plant residues decomposing in soil. *Phytopathology*, 57 (8):834, Aug. 1967. (Abstract.)

Linderman, R. G., and T. A. Toussoun. Breakdown in *Thielaviopsis basicola* root rot resistance in cotton by hydrocinnamic (3-phenylpropionic) acid. *Phytopathology*, 58(10):1431–1432, Oct. 1968.

Linderman, R. G., and T. A. Toussoun. Predisposition to Thielaviopsis root rot of cotton by phytotoxins from decomposing barley residues. *Phytopathology*, 58(11): 1571–1574, Nov. 1968.

Linderman, R. G., and T. A. Toussoun. Pathogenesis of *Thielaviopsis basicola* in nonsterile soil. *Phytopathology*, 58(12):1578–1583, Dec. 1968.

Weinhold, A. R., T. Bowman, and R. L. Dodman. Virulence of *Rhizoctonia solani* as affected by nutrition of the pathogen. *Phytopathology*, 59(11): 1601–1605, Nov. 1969.

Pyrolysis of Municipal Refuse

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Grant No. EC–00253–06
Funds Awarded: $126,728
Project Period: Sept. 1, 1963 to Feb. 28, 1970

OBJECTIVES: To determine the nature and quantity of the volatile matter resulting from the pyrolysis of refuse components. To investigate the possibility of recovering and using the combustible gases produced.

APPROACH: Initially, a small laboratory furnace was used to heat a closed retort charged with a small amount of refuse components such as paper, garbage, plastics, fats, oils, waxes, wood, leaves, and sewage sludge. The resulting products were analyzed both qualitatively and quantitatively. The calorific values of the refuse input and pyrolytic outputs were determined.

Later, a 13.5-in. diameter by 5-ft gasifier was built and used to investigate the pyrolysis process. About 200 lb of refuse per hr was pyrolyzed, and the output gases were collected and analyzed. The variables studied included feeding rate, rate of residue removal, rate of air supply, temperature and humidity of the air, depth of refuse bed, and refuse composition.

FINDINGS: By heating to 1,800 F, refuse organic matter is converted into almost equal weights of a char (carbon), combustible gas and CO_2, water, and organic liquids. The last is a complex mixture and is suitable as a low-sulfur fuel or chemical raw material. Sewage sludge, rubber, and plastics are rich in combustible gases and liquids.

The yields depend on the rate of heating; fast heating increases the yield of gas, while slow heating increases that of char. The char has properties of activated carbon, and these properties could be enhanced by further treatment with steam, CO_2, or air.

The organic liquids produced are 85 percent of the heavy (viscous) oil variety; 15 percent is a mixture of methyl alcohol, acetic acid, butyric, and propionic acids, methylethylketone, furfural, and others. Acetic acid is the major one of this group.

The gases consist principally of CO_2, CO, H_2, CH_4, C_2H_4, and C_2H_6. By removing the CO_2, a gas of about 700 Btu scf is produced. By catalysis, the gas can be upgraded to approach 1,000 Btu pipeline gas.

The gas producer has been built and preliminary trials have been made, but test data are not yet available. Experience and the preliminary trials indicate that a hot, combustible gas can be produced continuously by burning refuse with a restricted air supply, if the fusion (clinkering) of the ash at the grate can be controlled.

PUBLICATIONS

KAISER, E. R. Combustion and heat calculations for incinerators. *In* Proceedings; 1964 National Incinerator Conference, New York, May 18–20, 1964. American Society of Mechanical Engineers. p. 81–89.

KAISER, E. R. Prospects for reducing particulate emissions from large incinerators. *Journal of the Air Pollution Control Association,* 16(6):324. June 1966. (Condensation.)

KAISER, E. R. A new incinerator control meter is needed. *In* Proceedings; 1966 National Incinerator Conference, New York, May 1–4, 1966. American Society of Mechanical Engineers. p. 176–182.

KAISER, E. R. Chemical analyses of refuse components. *In* Proceedings; 1966 National Incinerator Conference, New York, May 1–4, 1966. American Society of Mechanical Engineers. p. 84–88.

KAISER, E. R., and S. B. FRIEDMAN. The pyrolysis of refuse components. *Combustion,* 39 (11):31–36, May 1968.

KAISER, E. R. Refuse reduction processes. *In* Proceedings; the Surgeon General's Conference on Solid Waste Management for Metropolitan Washington, July 19–20, 1967. Public Health Service Publication No. 1729. Washington, U.S. Government Printing Office. p. 93–104.

KAISER, E. R. Successful incinerators are not cheap. *Power,* 113 (9):78–79, Sept. 1969.

KAISER, E. R. The mounting problem of solid wastes. *Power,* 113 (10):62–63, Oct. 1969.

Pyrolysis of Solid Municipal Wastes

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Grant No. EC 00266-04
Funds Awarded: $96,280
Project Period: June 1, 1965 to May 31, 1970

OBJECTIVES: To investigate the feasibility of pyrolysis as an economic method of decreasing the volume of solid municipal wastes and of producing useful byproducts. To determine the effect of temperature, initial moisture content, and various types of refuse on the production of pyrolysis gases, liquids, and solids.

APPROACH: 4-in.-diameter pyrolytic converter was constructed and fitted with appropriate temperature and pressure monitors and loading and sampling openings. Several categories of refuse—paper, leaves, wood, glass, metals, etc.—were pyrolyzed separately and together to determine the effect of temperature, pressure, and waste composition on the production of gases, liquids, and solids. The Btu yield of the various pyrolytic products was determined at the different temperatures and pressures. The chemical composition of the various products was also determined.

After the performance of the 4-in.-diameter pyrolytic converter had been evaluated, larger converters, as much as 18-in. in diameter, were constructed and evaluated. In addition to the effects of temperature, pressure, and refuse composition, the effects of bulk density of the refuse and residence time in the pyrolyzer on the production of the various pyrolytic products were determined.

FINDINGS: Pyrolysis is technically feasible as a method of processing solid municipal wastes. The energy content of the products of pyrolysis—the char and the "crude vapor" (noncondensable gases, tars, and liquid organics)—is more than sufficient to sustain the process once it has been raised to the selected temperature. In equipment having the proper overall thermal efficiency, the process may be sustained by the combustion of the "crude vapor" only. The sulfur content in the tars of this vapor indicates that combustion of this vapor to sustain the process would give stack emissions well within Rule 53(a) of the San Diego County Air Pollution Control District governing such emissions (0.2 percent by volume as SO_2). The optimum temperature of pyrolysis with the minimum pyrolyzing time occurs at 1,500 F with material having a bulk density of around 15 to 20 lb/cu ft in both a 4-in.-diameter and 18-in.-diameter retort.

The liquid fraction from pyrolysis is sufficiently complex to warrant a detailed and extensive investigation. Although the estimated retail market dollar value of the liquid organic compounds in this fraction is impressive, it may well be that the cost of processing and separating this fraction to prepare the organic compounds for marketing would be so great as to render them noncompetitive.

The carbonaceous residue from the pyrolysis of municipal-waste combustibles represents a rich and reasonably easily transportable source of energy. The Btu yield of the carbonaceous residue from the pyrolysis of 1 to 1.25 tons of "typical San Diego combustibles" is equivalent to that of 1 barrel (42 gal) of Bunker "C" fuel oil. Moreover, the carbonaceous residue, when properly handled and activated, provides a material whose adsorptive potential is equal or superior to some activated carbons now marketed commercially.

Most plastic materials when pyrolyzed at 1,500 F depolymerize the carbon (plus inert fillers) and gas and thus present no operating problems. Glass softens during pyrolysis at 1,500 F but not to the extent that it becomes fluid. Thus glass should not present an operating problem. Iron and steel are unaffected by pyrolysis except that the solders used in fabrication of some cans melt and run. The quantity of metals so affected is so small as not to cause operating problems. Aluminum cans at 1,500 F behave much the same as glass.

Use of pyrolysis by any community whose solid waste classification approximates that of San Diego (i.e., by volume, 26 percent noncombustibles and 74 percent combustibles) would result in a significant reduction in the sanitary landfill space used annually. This potential annual reduction could reach as high as 70 percent, depending upon the character of the community's noncombustibles and the disposition of the char.

Pyrolysis of solid municipal wastes is a new and unique approach to this problem, but no capital and operating costs are available. It is estimated, however, that the overall unit cost of waste processing by pyrolysis would not exceed that encountered with incineration and could possibly be lower. Until such a time as an adequately sized pyrolysis unit is constructed and operated, the economic feasibility of this process when applied to solid municipal wastes will remain a matter of conjecture.

PUBLICATIONS

HOFFMAN, D. A. Burns refuse without a flame. *The American City*, 82 (2):102–104, Feb. 1967.

HOFFMAN, D. A. Pyrolysis of solid municipal wastes. Summarized in Engineering Foundation Research Conference, Solid Waste Research and Development, University School, Milwaukee, July 24–28, 1967. Conference Preprint No. F–1. 2 p.

JERMAN, R. I., and L. R. CARPENTER. Gas chromotographic analysis of gaseous products from the pyrolysis of solid municipal waste. *Journal of Gas Chromatography*, 6(5): 298–301, May 1968.

HOFFMAN, D. A., and R. A. FITZ. Batch retort pyrolysis of solid municipal wastes. *Environmental Science and Technology*, 2(11):1023–1026, Nov. 1968.

HOFFMAN, D. A. Processing of solid municipal wastes by pyrolysis. ASME. Paper No. 69-WA/PID–10. Presented at Winter Annual Meeting, American Society of Mechanical Engineers, Los Angeles, Nov. 16–20, 1969. 8 p.

Citric Acid from Citrus Wastes by Fermentation

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Grant No. EC 00258–03
Funds Awarded: $43,803
Project Period: Jan. 1, 1967 to Dec. 31, 1969

OBJECTIVES: To develop a procedure for converting the waste products of citrus-processing plants and citrus molasses into useful products, such as citric acid.

APPROACH: Selected canning plant waste waters having a high biochemical oxygen demand (BOD) content were used to dilute citrus molasses to the optimum sugar concentration for citric acid fermentation. Tapwater was used for the dilutions in preliminary studies. The latter determined the conditions and additives required to make the substrate suitable for the production of citric acid by strains of *Aspergillus niger*.

Three different sizes of fermenters were used for these studies. Fernbach Shake Flasks (0.3 liter) were used to determine the optimum concentration of molasses, the possible effects of interfering ions, and the optimum environmental conditions for citric acid production in shake cultures. In a 13.5-liter fermenter, the effects of aeration, stirring, pH, and temperature were studied. For the final phases, results from the first two studies were scaled up for pilot plant experiments with a 100-liter fermenter.

FINDINGS: *Aspergillus niger* NRRL 567 was used for the shake flask and pilot fermentation studies. Efforts are continuing toward obtaining cultures with higher and more specific acid production capabilities.

Stock inoculum cultures of *A. niger* NRRL

567 are maintained on Potato Dextrose Agar Slants. Inoculum culture is built up by transfer to shake flasks containing 10° Brix citrus molasses. The flasks are shaken for 3 days at 150 rpm, 28 C. An additional transfer is performed under the same conditions. The final inoculum is used at 3 to 5 percent of the total substrate volume in the pilot fermenter.

The most satisfactory medium was determined to be citrus molasses diluted to 20° Brix (approximately 9.5 percent total sugars) to which is added 1.65 percent (w/v) $K_4Fe(CN)_6$. Anti-foam is added to prevent foaming during sterilization. The total pilot plant volume is 100 liters. Sterilization is obtained at 121 C for 1 hr.

The best pilot fermentation results have been obtained by allowing growth to develop for the first 18 to 24 hr with stirring at 150 to 200 rpm, but without sparging air. The optimum temperature is 28 C and the pH is maintained at 4.5. After the initial growth period, sterilized air sparging at 0.5 scfm is employed for 24 hr at the same stirring rate. At the 48-hr point, aeration is increased to 1.0 scfm. Foaming is controlled by automatic anti-foam addition. Total fermentation varies from 76 to 86 hr and is dependent upon aeration and stirring rates.

The maximum citric acid yield obtained so far was 58 percent of theoretical and averages at 49 percent. Citric, succinic, and malic acids are the primary acidic fractions obtained in the fermented beer. These acids are generally obtained in ratios of 3 parts citric: 2 parts succinic: 1 part malic. Work is continuing to maximize citric acid production.

Garbage and Wastes for Mushroom Production

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Grant No. EF 00085–05
Funds Awarded: $79,740
Project Period: Jan. 1, 1959 to Dec. 31, 1964

OBJECTIVES: To investigate the production of compost material from municipal and industrial wastes capable of yielding mushrooms for human consumption and producing protein- and vitamin-rich fungus mycelia for animal feed and humus fertilizer.

FINDINGS: When properly blended, fortified, and composted, municipal and selected industrial solid waste materials will support mushroom growth and produce mushrooms in good yield and flavor. Analysis of the spent residue, composed largely of mushroom mycelia, showed it to contain more than 15 percent nitrogen. The residue was shown to have potential as a feed ingredient for ruminant animals. The following publications contain detailed results gained from this research project.

PUBLICATIONS

BLOCK, S. S. Developments in the production of mushroom mycelium in submerged liquid culture. *Journal of Biochemical and Microbiological Technology and Engineering,* 2(3):243, Sept. 1960.

RAO, S. N., and S. S. BLOCK. Experiments in small-scale composting. *Developments in Industrial Microbiology,* 3:326, 1962.

BLOCK, S. S., and S. N. RAO. Sawdust compost for mushroom growing. *Mushrom Science,* 53:14, 1962.

BLOCK, S. S. Effect of casing soils on the shape of the mushrooms. *Mushroom Science,* 5:321, 1962.

AMMERMAN, C. B., and S. S. BLOCK. Feed from wastes: feeding value of rations containing sewage sludge and oakwood sawdust. *Journal of Agricultural and Food Chemistry,* 12(6):539, Nov.–Dec. 1964.

BLOCK, S. S. Composting conversion of solid wastes for mushroom growing. *Biotechnology and Bioengineering,* 6(4):403, Dec. 1964.

BLOCK, S. S. Garbage composting for mushroom production. *Applied Microbiology,* 13(1):5, Jan. 1965.

BLOCK, S. S., and S. N. RAO. Small-scale composting for mushroom growing studies. *Developments in Industrial Microbiology,* 6:284, 1965.

Partial Oxidation of Solid Organic Wastes

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Grant No. EC 00263–03
Funds Awarded: $63,510
Project Period: May 1, 1966 to Apr. 30, 1969

OBJECTIVES: To investigate the possibility of converting organic solid refuse and sludges into useful products through a mechanism of partial combustion using limited quantities of oxygen in a fluidized bed.

APPROACH: Major components of domestic waste, such as paper and leaves, as well as dried sewage sludge, were studied as sources of useful products. These materials were finely divided and supported in an air-nitrogen stream containing less oxygen than required for complete combustion. Reaction was carried out in a vertical tubular reactor heated electrically.

Gaseous products of reaction evolved from the reactor were condensed and collected in a series of traps held at progressively lower temperatures. Analytical methods applied and utilized in the examination and identification of major components in the complex mixtures included wet chemical methods, gas chromatography used in conjunction with peak attenuation and a syringe reaction technique, infrared spectroscopy, and mass spectroscopy.

FINDINGS: Runs were made in a temperature range of 250 C to 1,000 C and with air-nitrogen mixtures ranging from zero to 100 percent air. Products obtained and identified included water, acetic acid, formic acid, formaldehyde, methanol, acetone, toluene, acetaldehyde, methyl acetate, ethyl vinyl ether, methane, carbon dioxide, carbon monoxide, propylene, ethylene, ammonia, ammonium carbonate, and hydrogen. In general, runs with high air-nitrogen ratios favored the formation of more highly oxygenated compounds, while a low air-nitrogen ratio promoted the formation of hydrocarbons.

PUBLICATIONS

SHUSTER, W. W. Partial combustion of solid organic wastes. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, II. Beaver Dam, Wis., July 22–26, 1968. Conference Preprint No. C–4.

Useful Disposal of Auto Bodies and Discarded Tires

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Grant No. EC 00275–01
Funds Awarded: $44,374
Project Period: Mar. 1, 1968 to Dec. 31, 1969

OBJECTIVES: To develop an effective method of compacting auto bodies and discarded tires into levee and foreshore protection materials with an interlocking configuration and a shape to permit optimum weight and cost per square foot coverage ratios. To design a complete facility to compact the discarded autos and tires and to develop suitable methods of preventing potential stream pollution resulting from their use.

APPROACH: A study of various configurations of compacted bodies was conducted to determine which configurations provided the maximum area of protection per ton of auto bodies and tires. Dies were constructed and incorporated into a portable car crusher to determine their effectiveness in producing suitable interlocking bales. In addition to compacting the auto bodies, attempts were made to incorporate discarded tires in the bales. The effect of heating the tires before incorporation into the bales was studied to determine if the softened tires help hold the bales together and provide some protection against stream pollution by partially coating the metal. Finally, the economics of a complete compacting operation was developed.

FINDINGS: The conclusions reached as a result of this study are as follows:

1. The use of compacted automobile bodies for large-scale Mississippi River levee protection is not economically feasible or practical, because of the vast quantities required in contrast to the relatively small tonnage of available automobile bodies within reasonable hauling distances.
2. The density of compacted automobile bodies (even with asphalt sand mixes added) is much too small (light) to replace the much denser riprap (broken stone) presently being used for construction work in the relatively high-velocity currents of the Mississippi River.
3. Compacted automobile bodies can be economically used (disposed of) in certain small-scale applications such as the hypothetical marshland shoreline erosion control work.
4. An observation based on the research team's association with this work indicates that some form of bounty or subsidy should be provided in the original purchase price of *all metal products* (not just automobiles) to assist in the economics of recycling *all metals* to the scrap processors in the interest of conservation of natural resources.

Biological Conversion of Animal Wastes to Nutrients

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Grant No. EC 00262–02
Funds Awarded: $41,634
Project Period: June 1, 1968 to May 31, 1970

OBJECTIVES: To investigate the digestion of poultry manure by flies and establish husbandry procedures for caring for fly larvae on a manure medium. To measure changes accomplished in poultry manure by these organisms, and their efficiency. To determine the value of the protein material as a feedstuff for poultry.

APPROACH: Fresh raw poultry manure was "seeded" with fly eggs to convert the manure energy into useful animal protein. Samples of the manure were analyzed for composition and nutritive value before and after digestion with fly larvae. Environmental conditions such as temperature, moisture content of the manure, humidity, and ratio of eggs to manure conducive to optimum conversion of the manure to pupal protein were studied. The protein material was analyzed for nutritive content, metabolizable energy, and ability to support growth in young chickens.

FINDINGS: Five species of Diptera (flies) were screened as potential means of converting poultry manure to high-quality protein for animal feed. *Musca domestica* (housefly) was selected because it reproduced in large numbers and required a minimum of time (5 to 10 days) to reach pupal stage. It was found that 3 g (about 60,000) of fly eggs to 4 kg of manure gave optimum yield of pupae. The fly larvae effectively reduced the problem of manure disposal by eliminating 60 percent of the moisture and 80 percent of the organic matter during the digestion period.

In addition, the wet, pasty, odoriferous manure was converted to a granular, stabilized, inoffensive product that was easily dried.

About 2 percent of fresh manure weight was harvested as dried fly pupae. These pupae continued 60 percent protein, comparable to fish meal as a protein supplement for starting chickens. The pupae are a good source of minerals and of some vitamins.

Since the housefly feeds on a wide variety of waste materials it may prove useful in solving other waste disposal problems. Through the controlled production of fly pupae, the number of wild flies would be reduced because their breeding sites are eliminated. While helping to solve a very difficult waste problem the housefly can be used as a protein supplement and aid in the control of wild, disease-carrying flies. Most of the fertilizer value is retained in the manure residue.

A poultry operation of 40,000 laying hens would produce 1,600 lb of dried fly pupae daily. At a price of 10 cents/lb, this would amount to $160/day. In addition, the manure residue could be used as fertilizer.

Feeding trials with growing broiler stock indicated that pupal protein can be used readily as the primary protein supplement in broiler diets. Pupae were used to replace soy bean oil meal, fish meal, meat and bone scraps, trace minerals, and B vitamin supplements in a standard broiler diet. The control diet resulted in slightly greater body weight, which was not, however, significant at the 5 percent level. The pupae diet resulted in slightly better feed efficiency, which again was not significantly different. Normally fly pupae would be included in poultry diets at about 5 percent of the diet instead of 30 percent as used in this study. The metabolizable energy of the pupae was found to be 1,149 cal/lb.

PUBLICATIONS

MILLER, B. F., and J. H. SHAW. Digestion of poultry manure by diptera. *Poultry Science*, 48(5):1844–1845, Sept. 1969. (Abstract.)

MILLER, B. F. Biological digestion of manure by diptera. Feedstuffs, 41(51):32, Dec. 1969. Presented at Pacific Southwest Animal Industry Conference, Fresno, Nov. 17, 1969. Sacramento, California Grain and Feed Association.

Biological Methane Formation

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Grant No. EC 00289–04
Funds Awarded: $169,517
Project Period: June 1, 1966 to May 31, 1970

OBJECTIVES: To obtain fundamental ecologic, nutritional, and biochemical information applicable to a general understanding of the process of methane formation from organic matter in natural systems. Special emphasis was given to those habitats, e.g., sewage sludge digesters and the digestive tracts of ruminants, in which anaerobic decomposition of organic wastes leads to methane formation.

APPROACH: Characterization of isolated methane bacteria included nutritional studies to establish the relationship of the nutrient requirements of the organism to the chemical composition of the natural habitat. The biochemistry of methane formation was studied in the *Methanobacillus omelianskii*, as well as in other methane bacteria of quantitative significance in natural environments, in order to compare the mechanism of methane production in various bacteria that produce methane from organic substrates, hydrogen, and carbon dioxide. Other aspects of the biochemistry of methane bacteria, e.g., electron transport systems and biosynthesis of cell constituents, were also studied.

Findings: Our work has resulted in great modification of theory about the bacteria concerned and intermediary metabolism involved in degradation of organic wastes by methane fermentation. Earlier studies indicated that methane-forming bacteria produced methane by degradation of acids, alcohol, and hydrogen produced from organic wastes by nonmethanogenic bacteria. We showed, however, that ethyl alcohol is not fermented by the methanogenic species *Methanobacillus omelianskii*. This species was shown to be a symbiotic association of two species. One species is nonmethanogenic and produces acetate and hydrogen from alcohol but cannot carry this out as a pure culture because the hydrogen produced inhibits its growth. The other species utilizes hydrogen produced by the first species to obtain energy for growth via reduction of carbon dioxide to methane. The maintenance of the low partial pressure of hydrogen allows the alcohol-degrading species to grow. Several species of bacteria have been shown to oxidize alcohols and lactic acid when grown in association with the hydrogen-utilizing methane bacteria. The work indicates that similar symbiotic associations of hydrogen-utilizing methane bacteria with nonmethanogenic species is probably responsible for degradation of fatty acids other than formate and acetate, and emphasizes the importance of methane bacteria, serving as hydrogen sinks, in allowing other bacteria to oxidize organic wastes more efficiently.

Studies have confirmed other recent work indicating that the hydrogen- carbon dioxide- and formate-utilizing species *Methanobacterium ruminantium* and *M. formicicum* are among the most numerous methane-forming species in sludge. Two new species utilizing these energy sources have been isolated. These studies demonstrated the great diversity of species of methane bacteria that utilize hydrogen-carbon dioxide and formate.

Studies on nutrients essential or stimulatory to growth of two of the more important hydrogen utilizing methanogenic species showed the great importance of acetate as a major carbon source, ammonia as the major nitrogen source, and sulfide as sulfur source. These bacteria are unable to utilize amino acids or peptides effectively either as carbon or nitrogen sources. Some strains require an unidentified growth factor in very small amounts. We previously developed methods for isolation of the factor from sewage sludge or rumen contents but could not obtain large enough amounts of factor for definite characterization. We now find that it is produced by other methanogenic species in amounts that should make identification feasible. Establishment of nutrient requirements of methane bacteria may give information of value to development of methods for more rapid anaerobic degradation of organic wastes.

Methods were developed, for the first time, for pure, large-scale cultures of methanogenic bacteria in culture media with hydrogen-carbon dioxide as energy source. This has made it possible to study effectively the biochemistry of these bacteria.

Knowledge of biochemical mechanisms by which a hydrogen-utilizing methane bacterium reduces carbon dioxide to methane has been increased. It has been shown that ATP in catalytic amounts and a low-molecular-weight, unidentified methyl carrier, present in extracts, are essential for methane formation from either carbon dioxide or methyl cobalamin. Studies on identity of the methyl carrier are in progress. The bacterium contains large amounts of a compound involved in electron transport that is fluorescent and dialyzable in the oxidized state but is bound to the nondialyzable fraction of the extract and is not fluorescent when extracts are reduced by hydrogen. The compound has been isolated, and studies on its identity and function in electron transport are underway. The cell extracts produce methane from the one carbon of pyruvate, the three carbon of serine, and from the one-carbon derivatives of N^{10} formyl-, N^5, N^{10}-methenyl-, N^5, N^{10}-methylene-, and N^5 methyl-tetrahydrofolate, and from methylcobalamin, but it is not yet known whether these compounds are significant intermediates in reduction of carbon dioxide to methane.

PUBLICATIONS

Bryant, M. P., E. A. Wolin, M. J. Wolin, and R. S. Wolfe. *Methanobacillus omelianskii*, a symbiotic association of two species of bacteria. *Archiv fuer Mikrobiologie*, 59(1-3):20-31, Aug. 1967.

BRYANT, M. P., B. C. MCBRIDE, and R. S. WOLFE. Hydrogen-oxidizing methane bacteria. I. Cultivation and methanogenesis. *Journal of Bacteriology*, 95(3)1118–1123, Mar. 1968.

LANGENBERG, K. F., M. P. BRYANT, and R. S. WOLFE. Hydrogen-oxidizing methane bacteria. II. Electron microscopy. *Journal of Bacteriology*, 95(3):1124–1129, Mar. 1968.

MCBRIDE, B. C., J. M. WOOD, J. W. SIBERT, and B. N. SCHRAUZER. Methylcobalt derivatives of vitamin Bs,12s, model compounds as substrates in enzymatic methane formation. *Journal of the American Chemical Society*, 90(19):5276–5277, Sept. 11, 1968.

WOOD, J. M., F. S., KENNEDY, and C. G. ROSEN. Synthesis of methyl-mercury compounds by extracts of a methanogenic bacterium. *Nature*, 220:173–174, Oct. 12, 1968.

ROBERTON, A. M., and R. S. WOLFE. ATP requirement for methanogenesis in cell extracts of Methanobacterium strain M. O. H. *Biochimica et Biophysica Acta*, 192(3): 420–429, Dec. 30, 1969.

ROBERTON, A. M., and R. S. WOLFE. Adenosine triphosphate pools in Methanobacterium. *Journal of Bacteriology*, 102(1):43–51, Apr. 1970.

KENNEDY, F. S., T. BUCKMAN, and J. M. WOOD. Carbenoid intermediates from the photolysis of haloalkylcobalamins. *Biochimica et Biophysica Acta*, 177(3):661–663, May 6, 1969.

WOOD, J. M. Environmental pollution by mercury. *In* R. R. Metcalf, and J. Pitts, *eds*. Advances in environmental science, v. 2. New York, John Wiley & Sons, Inc. (In press.)

Chemical Transformation of Solid Wastes

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Grant No. EC 00242–04
Funds Awarded: $136,562
Project Period: Oct. 1, 1966 to Sept. 30, 1971

OBJECTIVES: To classify and identify the chemical constituents of municipal and agricultural field solid wastes, to investigate methods of chemical transformation of these solid wastes to products of useful value, and to follow the development of suitable laboratory procedures with additional studies at the pilot-plant scale.

APPROACH: Initially, the chemical composition of the various portions of solid waste was determined. Efforts were then directed to the chemical transformation of the components of various wastes into useful products. Reactions being studied for the chemical transformation of cellulose include catalytic destructive distillation, high-pressure hydrogenation, and ether and ester formation. Experiments involving ether and ester formation are being conducted to unite nitrogen and phosphorus chemically to the cellulosic structure and, thus, to form a usable soil additive from the cellulose. In another series of experiments, cellulose is being extracted from waste materials by xanthate formation and the extract evaluated as a raw material for the commercial production of plastics.

The chemical transformation of plastic wastes to usable products through high-pressure hydrogenation, oxidation, destructive distillation, and extraction is being investigated. Metal extraction procedures are also being investigated to determine the feasibility of recovering various metals either as salts or in a pure state from solid waste.

The last phase of this study involves the application of useful transformation reactions to the solution of solid waste problems on a larger scale. The most promising chemical transformation reactions being studied in the laboratory will lead to studies of pilot-plant operation and associated engineering problems, and to an evaluation of economic factors.

FINDINGS: Information about the chemical composition of most wastes is available in the literature. Municipal refuse, straw, bark, wood, and paper contain high percentages of cellulose.

Destructive distillation and high-pressure hydrogenation of organic wastes produce a combustible gas, a heterogeneous liquid, and a carbon/ash solid residue. The liquid produced by hydrogenation of bark, for example, contains about 65 percent aromatic compounds and 35 percent aliphatic compounds.

The use of a catalyst or chemical reactant during destructive distillation affects the composition of the products.

The formation of cellulose esters and ethers from waste cellulose is a practical means of producing usable products. The cellulose in paper or straw can be acetylated by one of three processes (solution, fiber, or vapor) to produce cellulose acetate, which can be formed into a solid sheet under pressure and elevated temperature. Such a solid sheet should have applications as a construction material, laminate, container, and so forth.

Purified cellulose from wastes can be used as the raw material for the production of derivatives such as cellulose nitrate, methyl cellulose, and cellulose butyrate.

The cellulose of a complex waste such as municipal refuse can be partially purified by acid washing to remove the available metals and salts. Glass, rocks, and other dense materials can be separated by settling in a liquid medium. The metal content of straw can also be reduced by acid washing.

Straw pulp (cellulose) can be purified by using any of several techniques, including the nitric acid-pulping process and the soda process.

Waxes, fats, and oils can be removed from solid wastes by solvent extraction.

Cellulose xanthate can be formed from the cellulosic component of solid wastes. This compound is soluble in sodium hydroxide. Cellulose can be precipitated upon neutralization or derivatives such as zinc xanthate can be produced.

Phosphoric acid and urea can be used to form cellulose derivatives that are water insoluble. The ammonium salt of cellulose phosphate, or the amide, contains two plant nutrients that are not leached out by water. A greenhouse soil test indicates that this material is effective in stimulating plant growth when applied in the same nitrogen concentration as a commercial fertilizer.

The nitrogen content of cellulose can be increased by up to 12 percent by reaction with urea through the formation of cellulose carbamate.

The wide range of plastics being used today makes a single chemical treatment process most unlikely; however, some plastic materials can be dissolved in organic solvents and others can be degraded by acid or base treatment. Hydrogenation of plastics is a promising potential means of converting plastics to oil, but the appropriate reaction conditions and catalysts have not yet been defined.

The most promising chemical treatment processes for further study appear to be the use of waste cellulose by ester and ether formation, the hydrogenation of wastes to oil, and the nitrogen and phosphorus enrichment of wastes. Plans for economic evaluation and larger scale studies are underway.

Some industrial interest in waste utilization has been received, especially for cellulose utilization and plastic production.

Converting Incinerator Residue to Useful Materials

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Grant No. EC 00326–01
Funds Awarded: $50,734
Project Period: May 1, 1969 to Apr. 30, 1971

OBJECTIVES: To investigate the possibility of developing a process for the direct conversion of incinerator residue by calcining, melting, and slagging to a dense aggregate useful for road building or road surfacing or as a filler material for concrete. Because most municipalities are involved both in waste disposal and in road-building programs, a direct path to recycling and effective utilization of this waste product is envisioned.

APPROACH: A laboratory experimental evaluation of the thermochemistry of processes designed either to melt down, slag, or consolidate incinerated waste residues has been undertaken. From this investigation, parameters are emerging to permit recommendations for optimum burning and calcining conditions for waste products.

After the laboratory studies, preliminary design and cost estimates for a system to perform the needed thermochemical operation were made. A small pilot plant has been designed and constructed to handle a sidestream of ash from an existing municipal incinerator so that the final design criteria and economics for a full-scale plant can be developed.

FINDINGS: Philadelphia incinerator ash has been ground, fired, and milled to produce a ceramic oxide powder. An analysis for important elemental content has been made; it has been shown that this powder has thermal properties expected for the analyzed composition in terms of sinterability, fluxing behavior, etc., both alone and with additives. It has been possible, by these studies, to produce a very high-grade ceramic material that might be used for bricks or as a facing material.

For example, nonporous samples have been made with densities reproducibly at 2.90 g/cc and tensile strengths of 7,000 to 15,000 psi. Crushing strength (not measured) may be expected to be around at least 50,000 psi, and the material would fulfill any ordinary building requirements. Little modification of a brickworks would be necessary for the adaptation to a raw material of this type rather than to the ordinarily used clays.

Extensive firings with additions of lime have demonstrated the feasibility of turning the solid waste ash into cement powder and ultimately into some form of concrete. At present it appears that a composition allowing the formation of $2CaO.SiO_2$ and $2CaO.Fe_2O_3$ during firing at 1,350 C produces the best cement powder. Further study is rapidly continuing in this area. More importantly, the incinerator waste cannot only form a concrete mix but can also be used as an aggregate filler.

Ash has been given three different thermal treatments to produce aggregates for possible road use in both concrete and bituminous surfaces.

Both the Pennsylvania and Federal highway authorities have agreed to test aggregates produced, and it is hoped that they can proceed eventually to the actual laying of stretches of highway. Preliminary tests for friability, abrasion resistance, and chemical resistance are all encouraging. This area promises the most immediate use because cities that produce the solid wastes are also in the business of road building and topping; therefore, problems of logistics and economics are minimal, and this use involves probably the fewest changes in present policies. It is hoped that, later, the more remote possibilities can be brought to fruition once at least one scheme for usage is under way.

PUBLICATIONS

New twist in waste use. *Chemical Week*, 106(2):58, Jan. 14, 1970.

Degradation of Waste Paper to Protein

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Grant No. EC-00271-02
Funds Awarded: $165,160
Project Period: June 1, 1967 to May 31, 1970

OBJECTIVES: To evaluate a fermentation method of converting waste paper to a protein supplement for livestock feed, the specific objective being to obtain an extremely fast-growing, cellulose-digesting organism having a high nutritional/protein value.

Approach: The initial effort included isolation and screening of microbes to find suitable strains for rapid digestion of cellulose in a water medium enriched with hydrocarbons, oxygen, and nitrogen. The work centered on the isolation of hydrocarbon-utilizing, cellulose-digesting organisms by employing enrichment, sprinkle plate, percolation, and gardening isolation techniques. These organisms were purified and screened for growth. Cell yield, hydrocarbon utilization, cellulose degradation, and amino acid profiles were determined. The next phase involved the optimization of the fermentation process with a selected optimum growth organism. These studies investigated the following variables: pH, temperature, aeration, CO_2 requirements, trace elements, nitrogen sources, stimulators, and the effects of certain fractions of waste paper. A comparison of a batch versus a continuous fermentation investigated the effects of each on product quality and toxicity.

Findings: The initial phase isolated 367 pure cultures on n-hexadecane media from more than 70 different inocula of soil, compost, sewage sludge, and forest litter; 28 of these were found to be capable of attacking sodium carboxymethyl cellulose and lowering its viscosity. Only one proved to be capable of attacking purified cellulose, ball-milled newspaper, or newsprint. This culture is a fungus that grows well at up to 45 C, identified as *Aspergillus fumigatus.* Unfortunately, this organism is a known pathogen, and so cultivation on a large scale is believed to be not advisable.

More than 300 enrichment cultures were also developed on cellulosic substrates from similar inocula. These were tested in shake flask fermentations for ability to produce protein and utilized the aforementioned substrates. Only 10 enrichment cultures yielded greater than 0.2 mg of protein per ml in 5 days. Five of these, all fungi, were studied in shake flask fermenters in an effort to achieve optimum conditions for protein synthesis and cellulose utilization. The organisms isolated, *Myrothecium verrucaria, Trichoderma viride, Aspergillus fumigatus,* and *Cellulomonas* are from genera long known to be actively cellulolytic.

Myrothecium verrucaria gave the highest rates of protein synthesis of the fungi studied; therefore, scaled-up studies using 14-liter stirred-jar fermenters concentrated on this organism. Protein yield on ball-milled newspaper increased with substrate concentration up to the maximum used. A very simple medium containing dibasic ammonium phosphate, urea, and yeast autolysate proved optimal for protein synthesis and cellulose utilization. At a concentration of 4 g ball-milled newspaper per 100 ml medium, the maximum rate of cellulose consumption was 5.4 g per liter per day and the rate of protein synthesis was 0.3 g per liter per day. The maximum yield of protein obtained was 1.42 g/liter by a highly specific modified Biuret method, or 3.3 g/liter by the usual method of multiplying the total organic (Kjeldahl) nitrogen by 6.25. The amount of cellulose consumed under these conditions was 12.7 g/liter from an original 20.4 g/liter contained in 40 g/liter of ball-milled newspaper.

Chemical analysis of the dried final product indicates it may be a nutritious animal feed. The literature does not list *Myrothecium verrucaria* among the mycotoxin-producing fungi; however, preliminary feeding studies with mice and rats would be desirable before proceeding with pilot-plant construction in order to obtain some evaluation of its toxicity and dietary value.

The work accomplished was nearly sufficient to permit the design and construction of a pilot plant, although a few more stirred-jar runs using larger concentrations of ball-milled paper and perhaps larger concentrations of ammonium phosphate and urea may be desirable.

PUBLICATIONS

UPDEGRAFF, D. M. Semimicro determination of cellulose in biological materials. *Analytical Biochemistry,* 32:420–424, 1969.

Engineering Properties of Compacted Ash Fills

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Grant No. EC 00317–02
Funds Awarded: $40,455
Project Period: Mar. 1, 1969 to Feb. 28, 1971

OBJECTIVES: To determine the physical and engineering properties of both compacted fly ash and incinerated sewage sludge and to determine any environmental or health hazards associated with the use of these materials for fill purposes. Once the properties of the ash material are determined, decisions about their use as fills to support heavy loads can be made.

APPROACH: The engineering properties of fly ash and incinerated sewage sludge are being determined. The index properties and composition of ashes are being defined by various methods, including grain size distribution, specific gravity, grain shape, and ignition loss tests among others. The compaction characteristics are determined by impact compaction and kneading compaction tests. Strength properties of compacted fly ash are defined by unconfined compaction tests, CRB tests, triaxial compression tests, and ash-hardening tests. The settlement and compressibility behavior are determined by an *in situ* measurement of the coefficient of compressibility of the ash fills by the use of a Dutch cone penetrometer. Frost susceptibility is determined by standard grain size analysis and frost heave tests. The effect on strength and frost susceptibility of low-level additions of cement, lime, and asphalt is also being determined.

The hazards associated with the implacement of ash fills are being investigated. Analysis of the ash leachate reveals the pH, BOD, COD, total soluble salt content, major ions, and toxic compounds. The corrosiveness of the compacted ash is determined by its bulk electrical resistivity, redox potential, and weight loss coupon analysis. Ash fill aggressiveness toward vegetation and moisture retention characteristics are also being determined.

FINDINGS: The fly ash under investigation was obtained from four coal-fired stations in Michigan. The fly ashes were selected as representative of the typical range of ashes produced by coal-fired power stations. The sewage sludge ashes were obtained from 10 treatment plants scattered all over the nation. The sewage sludge ashes were likewise selected to provide a range of possible ash types.

The fly ash study is focusing primarily on the compressibility and frost susceptibility of this material, because these are the two properties about which least is known and the ones that might preclude its use as a structural fill material in engineering practice. The sewage sludge ash study, on the other hand, is attempting to characterize this since there is no published information on it at all.

Index property tests and chemical composition analyses have been completed on both types of ashes. Both the sewage ash and the fly ash are predominantly silt-size material.

Strength-compaction tests have also been completed on all ashes in addition to age hardening tests and lime-cement stabilization tests. Strength falls off markedly for samples compacted wet of optimum; this trend is even more pronounced with compacted fly ash. Most ashes, particularly the sewage ashes with large free-lime contents, exhibit as much as a twofold increase in unconfined compressive strength with time. The addition of as little as 3 percent cement by weight to nearly all the sewage sludge ashes is sufficient to give them enough strength when compacted to meet easily minimum strength requirements for subbases in road construction.

When mixed with the right amount of water and about 10 percent cement by weight and then compacted statically to about 5,000 psi, some of the sewage ashes approach the strength of a lean concrete. As a result we are preparing now to manufacture some trial building blocks for experimental purposes from sludge ash supplied by the Pontiac, Michigan, plant.

A frost heave testing facility has been designed and constructed; experiments are presently under way on various compacted ashes. The pH of all the sewage ashes has been measured and found to be quite alkaline (pH 10 to 12). One of the sewage ashes (from Pontiac, Michigan) is quite corrosive when it comes in contact with metal.

PUBLICATIONS

GRAY, D H. Properties of a compacted sewage ash. *Journal of the Soil Mechanics and Foundations Division*, American Society of Civil Engineers, 96(SM2):439–451, Mar. 1970.

High-Energy Gas from Refuse Using Fluidized Beds

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Grant No. EC 00399–02
Funds Awarded: $272,556
Project Period: Jan. 1, 1969 to Dec. 31, 1970

OBJECTIVES: To investigate several possibilities in the operation of a fluidized bed of sand for the disposal of solid waste. Complete combustion, incomplete oxidation, and pyrolysis are the three alternative processes available for the recovery of energy content of refuse in a fluidized bed.

APPROACH: Cellulose and other polymeric materials are contacted with air, inert gas, steam, and combinations of these gases in a fluidized bed. This results in oxidation, pyrolysis, and anaerobic decomposition reactions. For each type of operation, an attempt is made to recover evolved heat or organic compounds, or both, and gaseous hydrocarbons in varying amounts. Maximizing the yields of hydrogenated gas of high heating value is emphasized. Temperatures of 1,300, 1,500, and 1,700 F and pressures from atmospheric to 100 psi are used together with several homogeneous semifluid feeds and several feed rates. Fluidization variables of particle size and gas velocity are investigated, and the product is analyzed for heating values and carbon-hydrogen ratios. Residues are analyzed for ash, sand, and unburned solids.

FINDINGS: Investigations have shown that the gaseous products resulting from the thermal decomposition of cellulosic materials are sensitive both to the rate of heat transfer to the sample and to the temperature of the surroundings. At high heat transfer rates the cellulose polymer decomposed to hydrogenated gases and at low rates more oxygenated gases were formed. The fluidized bed results in rapid heat transfer, and this leads to higher yields of hydrogenated materials. The quantitative values have not been established.

A mathematical model developed to describe the pyrolysis or pyrolysis-combustion of cellulosic material takes the following factors into consideration: (1) heat transfer by conduction, (2) heat transfer by radiation, (3) sample geometry, and (4) bulk flow of pyrolysis out of sample. The model is useful in explaining many experimental observations appearing in literature as well as the unique effects contributed by the fluidized bed.

Steady-state experiments have been performed on the conversion of an aqueous slurry containing 20 percent solids in the fluidized bed. These solids were mainly 1-methylaminoanthraquinone or other insoluble organic dyes. Experimental parameters were airflow rate, bed height, and bed temperature. It was observed that the organic dye compounds readily underwent pyrolytic decomposition owing to the high heat transfer rates present. At temperatures of 1,600 F oxidation followed within the bed in a smooth manner. At lower temperatures a noticeable fraction of the decomposition products emerged from the bed, especially at low air rates. This latter material underwent oxidation in the free-board space or was elutriated.

Kinetics of Porteous Refuse Hydrolysis Process

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Grant No. EC 00279–02
Funds Awarded: $70,348
Project Period: June 1, 1968 to May 31, 1970

OBJECTIVES: To determine the reaction kinetics for the formation of glucose from cellulose-containing materials found in solid wastes, and the subsequent decomposition of the glucose in a high-temperature, low-acid-concentration hydrolysis process. To conduct a process design and economic evaluation of the hydrolysis process for the fermentation production of ethanol from cellulose found in solid wastes.

APPROACH: The rate at which glucose forms and decomposes at various temperatures and acid concentrations was determined experimentally in a small batch reactor. Once the reaction rates were known, the time to optimum glucose yield could be calculated by using the relationship for consecutive first-order reactions.[1] Next a reaction vessel was designed and constructed to permit the separate heating of a cellulose slurry and an acid solution. Once the desired reaction temperature was obtained, the reagents flowed through a mixing tee and a reaction chamber. The reaction was then quenched, and the amount of glucose produced was determined to confirm the reaction rates found in batch operation. Once reaction rates were accurately known, a full-size hydrolysis plant was designed and an economic evaluation performed to determine the cost of producing glucose for a fermentation process.

FINDINGS: The acid hydrolysis of cellulose in paper follows a sequential, first-order, kinetic model, namely, cellulose $\xrightarrow{k_1}$ sugar $\xrightarrow{k_2}$ decomposed sugars. The rate constants k_1 and k_2 have been determined as a function of temperature, in the range of 180 to 230 C, and acid concentration, in the range of 0.2 to 1.0 percent. The reaction time for maximum sugar yields was determined from the model.

A plant design for the hydrolysis and an economic analysis based on the kinetic model indicate that sugar can be produced for between 1.8 to 3.0 cents/lb. This is in the range to be competitive with sugar from molasses. The major factors affecting the economics are the plant capacity, the percent cellulose in the refuse, the dumping fee, and the solid-to-liquid ratio of the paper slurry feed to the reactor.

A small, tubular, continuous, isothermal reactor was constructed to study the operating parameters and further improve the economics of the final plant design. The effect of impurities in the refuse on the hydrolysis and the fermentation of the sugar to alcohol was studied.

Laser-Mediated Lignin Solid Waste Fermentation

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Grant No. EC 00278-02
Funds Awarded: $33,689
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To determine the effects of laser and irradiation energy sources on the configuration of lignin substrates and to evaluate biologic effects of such modification processes. Process are being developed by which the lignin polymer can be degraded completely for use as a carbon source or be modified by microbial transformations to yield chemical intermediates of commercial interests.

APPROACH: Initial studies were concerned with photolytic effects on microbial fermentation of model compounds of which it is thought that lignin is composed. The photolytic irradiation interaction with model substrates was conducted with mercury arc photolytic energy. Areas of the ultraviolet, visible, and near infrared spectrum, were investigated by the use of appropriate filters. After treatments at various times and temperatures, analytical procedures were used to detect possible changes in configuration, linkages, and sulfur state. After this treatment, enrichments from soils, sewage, and rotted woods were used to develop competent cultures, followed by fermentation and chemical analysis.

In the next phase, a laser unit producing energy at the wavelength determined optimum in the study with mercury arc lamps is being used. The laser energy source is coupled with a fermentation vessel and used for the study of batch fermentation by specific organisms, to allow study of the physiologic aspects of use of photolysis product.

FINDINGS: During this research period, definite improvement in biological availability of lignin-sulfonate by use of photooxidative modification has been shown.

Work with both fungal and bacterial growth systems in pure cultures indicated that photolysis during low or high pH conditions, in comparison with pH 7.0, permits retention and utilization of a greater portion of ligninsulfonate carbon. By use of varied photooxidative conditions, it has been possible to render residual ligninsulfonate carbon as much as 60 percent bioutilizable in one process step. Without photolytic modification negligible bioutilization is observed. Maximum bioutilizability is observed after decoloration of the ligninsulfonate solution.

Research of this period has also given information germane to the present and future design of lasers to be used in such processes. Light wavelengths of less than 210 mm are required, and as little as 0.5 watt of output power should give the potential for an efficient single-pass treatment system.

Information on the nature of biologic responses to photooxidized ligninsulfonates has also been obtained. Fungi appear to utilize lower weight polymeric products from earlier photomodification as well as aromatic lignin subunits, while bacterial responses appear to be related primarily to the utilization of aromatic subunits produced in later stages of the photooxidation process. Microbial economic utilization coefficients with photolytically produced ligninsulfonate fragments can be equated to use of conventional carbon sources at the beginning and end of the photolysis period.

Judged on presently available information, further applications of this research can be considered. These biologically improved ligninsulfonates will be amenable to efficient degradation in waste treatment plant and lagoon systems and also will be available for production of single-cell protein. In addition, this treatment approach can be applied to diverse lignin-containing materials and also to pesticides and chemical wastes. This solid waste utilization approach can become a major factor in creative management of recalcitrant waste products.

PUBLICATIONS

KLEIN, D. A., J. P. ELDRIDGE, and R. C. ROCKHILL. Photofermentation of recalcitrant molecules: Initial studies with lignin sulfonate and lignin model compounds. *Bacteriological Proceedings*, 69:16 (A105). 1969. (Abstract.)

KLEIN, D. A. New weapon for anti-pollution arsenal. *Oregon's Agricultural Progress*, 16(1):6–7. 1969.

KLEIN, D. A., R. C. ROCKHILL, J. P. ELDRIDGE, and J. E. PARK. Fungal and bacterial responses to photooxidized lignin sulfonate substrates. *Tappi*, 53(8):1469–1472, Aug. 1970.

Noncombustive Disposal of Solid Agricultural Wastes

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Grant No. EC 00255–03
Funds Awarded: $216,339
Project Period: Feb. 1, 1967 to July 31, 1970

OBJECTIVES: To determine the feasibility of shredding woody wastes and incorporating them into the soil and to evaluate the resulting effect of this practice on soil-borne plant pests, soil properties, and eventual plant growth. Specifically, to determine whether adding wood chips to the soil in various orchards increases the inoculum potential of the root rot fungi *Armillaria mellea* and *Phytopthora* spp. and of the wilt fungus *Verticillium albo-atrum* and favors the reproduction of the shot-hole borer, soil structure alteration, and water penetration.

APPROACH: Mechanical shredding operations were carried out at several demonstration plots, the time and costs of these operations and the effect on soil chemistry being emphasized. Laboratory and field experiments were performed to determine the effect of the addition of the shredded waste on fungi and diseases in the vegetation and to investigate their control by chemicals. Special attention was given to the effects of climate, differences in plant species, and the rate of decay of the shredded material.

FINDINGS: Shredding experiments were established in 21 orchards representing the major fruit crops in central portions of California. The biological processes evaluated after incorporation of waste into the soil require considerable time before changes can be noted. Only two seasons' wastes have been chipped and turned into the soil, and no conclusive results are yet available. Certain trends have, however, been noted.

Most of the incorporated waste is found in the top 4 to 5 in., but occasionally pieces are found as deep as 8 to 10 in. A few pieces the size of a man's thumb have been found to be infested with *Armillaria*, and the fungus was viable. Although the numbers involved were small, the results indicate that such pieces can be infested and thus present a potential threat in increasing rate of spread of the fungus. No fine chips have ever become infested, either in field trials or in special experiments where the material was buried by hand and inoculated with the fungus. In the latter experiments, *Armillaria* easily infested pieces 4 in. long and varying from ½ to 2 in. in diameter.

While laboratory studies have shown that *Phytophthora* can infest nonsterile wood chips, isolations to date from field plots have not shown any significant change, either an increase or a decrease in the inoculum potential.

A significant preliminary result with *Verticillium* is that when infected olive branches were chipped and added to the soil, no contamination of the soil occurred.

One aim of the insect studies was to prevent the generation of orchard wastes, as would be the case when borers attack healthy tree branches. Preliminary work has shown that latex paint applied to branches prevents the insects from laying eggs.

An interesting observation has been made on soils contained in large cylinders, some of which have received shredded wastes. Following heavy rains, soils without chips had water standing on the surface for at least 24 hr. No water was standing on treated soils. In other experiments, differences in water release properties and hydraulic conductivity indicate that a change in irrigation practice may be needed to manage properly fields treated with wood waste additions.

Photosynthetic Reclamation of Agricultural Solid and Liquid Wastes

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Grant No.: EC 00272–03
Funds Awarded: $93,838
Project Period: June 1, 1967 to May 31, 1970

OBJECTIVES: To study the application of an integrated system involving an anaerobic digestion phase and an algae production phase to the disposal of agricultural wastes, especially animal manures, and to the reclamation of the plant nutrients and water contained in the waste.

APPROACH: A plant consisting of a digester, algae pond, equipment for harvesting algae, and necessary ancillary equipment was assembled at the University of California, Richmond Field Station. Animal wastes were fed to a 150-gal concrete anaerobic digester and fermented. The effects of solids content, pH of the waste, temperature, detention period, loading, and method of operation on the digestion process were determined with animal wastes. Wastes were characterized not only on the basis of origin but also on that of C/N ratio, nitrogen content, pH, and total and volatile solids content. The digester was operated both as a batch process and as a continuous process to determine digestion efficiencies under both conditions. Digester performance was judged on the basis of gas production, extent of volatile solids destruction, pH, volatile acid concentration of the sludge, and the physical characteristics of the sludge.

The effluent from the digester was fed directly into a 5,500-gal variable-depth algae pond. The effects of temperature, detention time, culture depth, mixing time, type of waste effluent, and CO_2 concentration on algae growth were determined. The performance of the pond was evaluated on its overall conversion efficiency and by its effluent quality after the algae had been removed. The algae were harvested by methods proved practical and economical in previous research, i.e., initial concentration, dewatering, and final drying.

FINDINGS: In choosing a subject for the first phase of the research project from among the various solid waste producers in food production, it was decided to select chickens, i.e., egg production hens, because of the relative ease of housing and rearing them, and equally importantly, because the disposal of chicken manure constitutes a major problem not only in California but also in many other States. Accordingly, the objectives and procedures outlined in the previous section were directed toward the management of chicken wastes.

Early in the study, it became apparent that to ensure a reliable and uniform source of manure for experimentation, it would be necessary to install a colony of egg layers at the site of the study. Therefore, a 14- by 14-ft poultry enclosure was designed and constructed and was stocked with 113 20-week-old white leghorn pullets caged in batteries, each of which held four hens (0.45 sq ft/hen). A Fiberglas-coated trough was placed below each row of batteries to catch the chicken excreta. Once each hour a tipping bucket (8.3-gal capacity) mounted at the end of each of the troughs discharged its contents (water from the algae pond) into the trough to flush the excreta down the trough and into a sedimentation tank. It was important that the wet weight of manure solids in the slurry discharge into the sedimentation tank be less than 3 percent of the slurry weight (manure plus water). At this or smaller concentrations, more than 70 percent of the solids settle out of suspension in less than 15 minutes. A submerged sump pump moved the supernatant from the sedimentation tank to the algae pond, and a slude pump moved the settled solids to an anaerobic digester. Supernatant from the digester was discharged into the algae pond, while the digested sludge periodically was wasted to the environment. Pond culture either was recycled directly to the tipping buckets or was first processed for algae removal and then discharged into the tipping buckets. Provision was made for discharging the overflow when necessary. Tapwater served as drinking water for the hens. The overflow from the drinking water troughs was discharged into the manure troughs and thereby served the dual purpose of keeping the troughs moist and of constituting makeup water. During the winter months, when algal growth was negligible, a sump pump with an above-the-surface discharge served as an aerator to keep the pond aerobic and thereby prevent the development of odor nuisances.

At the time of this writing, the indicated required pond area per bird was 2 sq ft. With the pond depth at 12 in. or less, and water being allowed for in the digester, sedimentation tank, and tipping buckets, the water needed to establish the overall system would be about 15 gal/hen. The amount of water needed to maintain the system, once it was established, would be a function of evaporation plus spillage minus overflow from the drinking water troughs.

At an average detention time of 23 days, gas production was about 12 cu ft/lb volatile solids introduced. Although low at first, the methane content of the gas steadily increased until at the time of this writing it constituted from 50 to 60 percent of the gas. Overall volatile solids destruction was about 55 percent. Of the total solids input, approximately 70 percent was converted to digester gas. Only a fraction of the algae growing in the pond was harvested. Harvesting was done by "natural" settling and by centrifugation. The potential algal yield in the pond was equivalent to 30 to 40 tons (dry wt) of algae/acre-year. Overall photosynthetic conversion of visible light energy to algal cellular material ranged from 0.64 to 2.8 percent.

An analysis of the integrated system indicated that biological activity in the sedimentation tank, digester, and algae pond decreased the total solids by 60 percent; the volatile solids by 62 percent; the total unoxidized nitrogen by 45 percent; and the energy input (exclusive of light) by 56 percent.

An economic evaluation based on an integrated system of 100,000 egg layers and the application of the *low loadings* and the *high cost* and *overdesigned* components used in the research indicated that the waste-handling costs of the system would be at the most 2 cents per dozen eggs. If the value of the algal crop were credited to the operation, the net waste-handling cost would be 1 cent or less per dozen eggs.

PUBLICATIONS

Golueke, C. G., and S. A. Klein. Treating combined liquid and solid wastes. Presented at 1968 Conference of California Water Pollution Control Association, Santa Rosa, April 24–25, 1968. 15 p.

Ichikawa, K., C. G. Golueke, and W. J. Oswald. Biotreatment of Steffen House waste. *Journal of the American Society of Sugar Beet Technologists*, 15(2):125–150, July 1968.

Dugan, G. L., C. G. Golueke, and W. J. Oswald. Photosynthetic reclamation of agricultural solid and liquid wastes. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, II, Beaver Dam, Wis., July 22–26, 1968. Conference Preprint No. E–1.

Dugan, G. L., C. G. Golueke, and W. J. Oswald. Photosynthetic reclamation of agricultural solid and liquid wastes. Presented at 42nd Annual Conference, Water Pollution Control Federation, Dallas, Oct 5–10, 1969. 13 p.

Golueke, C. G. Chemical and microbial characteristics of urban solid wastes. [Presented at Annual Meeting, American Society for Microbiology, Miami Beach, May 4–9, 1969.] 17 p.

Poultry Offal Silage as a Feed Ingredient

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Grant No. EC 00269–02
Funds Awarded: $32,991
Project Period: June 1, 1968 to May 31, 1970

OBJECTIVES: To develop a method of producing and using silage from poultry offal (slaughtering wastes including intestines and contents, the feet, and the head) as a feed for chickens.

APPROACH: Poultry offal silage is presently prepared by mixing ground offal with a source of carbohydrate, usually corn meal, and water and letting it sit for 1 week. No specific attention is paid to the kinds of organisms present. This research effort investigated the possibility of improving the nutritive value of the silage. One approach was to investigate the effect of various carbohydrate sources and the resulting predominance of particular organisms that utilize them. When a particular organism was found to be well suited to the production of a good silage, that organism was isolated, developed, and inoculated into a sterilized mixture before fermentation to determine if uniformly superior silage could be produced from a nutritive standpoint.

The criterion of nutritive quality was the performance of the silage in feeding experiments. A standard soybean meal-corn ration enriched with all the known required vitamins and minerals was added to this ration at the expense of corn, since the silage and corn have approximately the same protein content. Attention was paid to keeping the energy levels of both diets equal by adding fats to the basic diet to offset the extra fat contained in the silage. Chicks were fed both diets from the day of hatching, and the growth rates of the chicks were used as an evaluation of nutritive quality. As preparations of the silage were made, samples were taken, and the value as a feed ingredient was assessed from its content of known nutrients.

FINDINGS: When poultry offal silage is used as a part of the corn-soybean meal basal, a growth response of 5 to 10 percent has been obtained. Supplementing the diet with antibiotics, zinc, and molybdenum or increasing the known vitamin levels do not increase chick growth under these conditions. In a field trial with chicks raised under practical conditions a growth response of 6.8 percent was obtained. The chicks were raised to market weights at 8 weeks of age. The growth stimulant is water soluble, but efforts to extract it with organic solvents have been unsuccessful. It is stable to autoclaving at 15 lb pressure for 30 min.

Radiolytic Hydrolysis of Cellulose

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Grant No. EC–00362–01Al
Funds Awarded: $25,707
Project Period: Feb. 1, 1970 to Jan. 31, 1971

OBJECTIVES: To determine the effect of gamma radiation on the hydrolytic conversion of cellulose to fermentable sugars. To determine the feasibility of using radioactive wastes as intense gamma radiation sources for large-scale irradiations of cellulosic materials.

Approach: Initially a gamma radiation chamber will be designed and constructed to facilitate the study of irradiation hydrolysis. The effects of irradiation dose, dose rate, chemical environment, and temperature on the hydrolysis of various types of cellulose to produce fermentable sugars will be determined. The effects of these parameters on the rate of decomposition of the fermentable sugars produced in the hydrolysis reaction will also be determined. The effect of irradiation on the hydrolysis reaction will also be determined and related to the time at which it is applied—before or during the chemical hydrolysis reaction. As a result of these determinations, conditions for optimum sugar production will be defined. The second portion of this project is related to solving problems associated with the use of radioactive wastes as the gamma radiation source. The amounts and associated activities of the various radioisotopes produced as fission products in the nuclear power industry in years to come will be estimated. The most practical form of the gamma radiation source is being determined, and a facility will be designed in accordance with Atomic Energy Commission criteria for the storage and use of these wastes.

Findings: This grant was awarded on Feb. 1, 1970, and findings are not yet available.

Reclamation of Energy from Organic Refuse

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Grant No. EC–00364–01
Funds Awarded: $40,390
Project Period: Aug. 1, 1969 to July 31, 1972

Objectives: To determine the operating parameters for the biologic conversion of organic solid waste to methane by use of anaerobic digesters. To evaluate the potential operating problems associated with the proposed process and determine the potential for energy reclamation.

Approach: The effects of operating temperatures, retention times, and solids content are being determined and related to the energy yield from the methane fermentation, the reduction in quantity of organic refuse, and the characteristics of the residue. Fifteen-liter plexiglass digesters will be used for the laboratory study. Digester temperature will be closely controlled, and mixing will be provided by mechanical stirrers. Residential refuse will be used as collected with no separation of the noncombustibles, plastics, and rubber before it is placed in the digester. Initial runs will be made at 35 C to determine the solids content in the feed required for the optimum production of methane. Similar studies will be conducted at temperatures up to 60 C.

Control of the digestion process will be based on the pH, the concentration of volatile acids, and the gas production. Daily gas production will be measured and the composition of the gas determined. The pH will be maintained in the optimum range of 6.6 to 7.6. No attempt will be made to control the volatile acids, except during the startup period, at which time the loading will be controlled to keep the volatile acid concentration less than 2,000 mg/liter.

Process evaluation will be based on the efficiency of the conversion of the organic solids to methane gas and on the energy value of the resulting gas mixture. Solids balances will be run on the systems and correlated with methane production.

Findings: Progress to date has been limited to constructing the laboratory units, obtaining the shredded domestic refuse from the BSWM's Center Hill Laboratory, and analyzing the chemical characteristics of this refuse prior to starting the experimental runs.

Refuse Reclamation by Size Reduction and Separation

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Grant No. EC 00333–01
Funds Awarded: $62,685
Project Period: June 1, 1969 to May 31, 1971

Objectives: To demonstrate the feasibility of separating refuse into several components in an automated manner partially through the use of a vortex classifier mill to effect both size reduction and coarse separation. A subsidiary aim is to determine which components of refuse may be separated with maximum benefit-cost ratio.

Approach: This project consists of seven phases of research, some of which run concurrently. The first phase, which runs for the 2 years of the project, will investigate a vortex classifier and its ability to provide partial size reduction and coarse classification of refuse components. During the second phase, salvageable refuse components will be identified and listed with present typical gross salvage values. The various refuse components' properties will be identified during the next phase of the project. Among these are density or specific weight, thermal conductivity, radiation emissivity, dielectric constant, paramagnetism, gamma-ray absorption, and drag coefficient. A search will be conducted to find the minimum number of sensors that positively identify all the components of refuse listed in phase two. A preliminary design of a hypothetical separation system will be made in phase four.

The plant will be designed to pass the refuse through a series of sensors and provide a means of removing the refuse components into various categories. During phase five a cost benefit analysis of various systems designed to remove different refuse components is being made.

Phases six and seven deal with the design and construction of a 75 ton/day pilot plant to accommodate virtually all the types of trash currently found in municipal refuse. These phases are not part of the currently funded effort. It is envisioned that a maximum number of categories of refuse will be separated in the pilot plant so that each sensor and removal device can be evaluated.

Findings:

1. The vortex device does not seem to be of much value as a pulverizer of general mixed refuse. It does seem to work well with brittle materials, e.g., glass, or with paper or textiles. We believe from our model tests that its value will be greater as a classifier, and we are designing a test rig to investigate the flow patterns of the air and the particles (modeling these as the flow of dense particles in water) so that we may later design a half- or full-scale classifier.

2. We believe that we have two promising approaches to mechanized sorting. One is the method suggested in our proposal, whereby shredded refuse would be scanned by a series of sensors and a decision would be made on the basis of the readings obtained about which of several categories the material would be switched to. We have found that microwave and infrared sensing shows promise, and we are investigating further. The second method is applied to unshredded single items of refuse, e.g., a bottle, or a newspaper, or a can. A signature is obtained from a sensor that reads a mix of properties and characteristics. We

have found that the readings from an accelerometer attached to a ball dropped onto each item gives enough information to permit coding of most useful and nonuseful items. We are pursuing this line of approach vigorously.

3. We have made a preliminary economic analysis, which seems to indicate that a reclamation plant should be a favorable alternative to an incinerator when the alternative costs of disposal are high, e.g., $10. This figure will come down when mechanized sorting is available and will come down more when governmental action prevents wild fluctuations in the price of secondary materials.

Single-Cell Proteins from Cellulosic Wastes

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Grant No. EC 00328-02
Funds Awarded: $190,157
Project Period: Mar. 1, 1969 to Feb. 28, 1971

OBJECTIVES: To isolate and identify cellulose-digesting organisms, to study the growth of these organisms in the presence of cellulose, and to investigate the optimal conditions for enzyme production during growth of the various cellulosic wastes. Once suitable organisms were isolated, a chemical-microbial pilot plant was operated to convert various cellulosic wastes to single-cell proteins. The nutritional value, digestibility, and toxicity of the single-cell protein are being determined.

APPROACH: Before the research grant award an organism was isolated that is capable of breaking down cellulose. This organism was used as the model organism for designing the initial stages of the pilot-plant studies. A search is being made to isolate other organisms capable of utilizing cellulose. These organisms are grown in the presence of substrates prepared from cellulosic wastes such as bagasse, rice straw, wheat straw, and paper wastes so that the organisms capable of metabolizing the various wastes can be determined.

With use of BSWM contract funds, a continuous chemical-microbial plant was designed and constructed for the production of single-cell protein. The process consists of an initial size reduction unit, a mixing area where the cellulosic wastes are pretreated with sodium hydroxide, an oxidation step whereby the lignin is depolymerized, a sterilization step, an acid neutralization step, and finally fermentation. Techniques for refining and processing the cell yield are being developed and designed with the necessary amount of flexibility to ensure optimum conditions.

The untreated whole cells, disrupted cells, and various protein fractions derived from the cell are evaluated both chemically and biologically. Chemically, the nitrogen content, protein content, amino acid composition, lipid composition, and vitamin and mineral content of the cells are determined. A study with rats is determining the toxicity, digestibility, and nutritional value of the harvested cells.

The chemical-microbial pilot plant has been constructed and is being operated at NASA's Mississippi Test Facility.

FINDINGS: A cellulose-decomposing aerobic and mesophilic bacterium has been isolated from the soil of a sugar cane field and identified as a member of the genus *Cellulomonas*. This bacterium produces the cellulase enzymes that cause subsequent hydrolysis of the cellulose to simple sugars. These hydrolytic products then serve as the substrate for microbial growth. The microbial cells are harvested for their protein, and this product is usually referred to as single-cell proteins. The enzymatic hydrolysis of cellulose is not new. E. T. Reese and R. G. H. Siu, as well as others, have studied fungal cellulases extensively, but the growth rates of fungi are many orders of magnitude slower than those of bacteria and furthermore, the amount of protein is considerably less in fungal products. Since production costs vary directly with growth rates this would indicate that the use of bacteria to dispose of cellulosic wastes may be a more practical approach.

When bagasse, the residue from sugar cane after the sugar is extracted, is used as the sole carbon source for the growth of *Cellulomonas,* a yield of 20 lb of cell product is obtained for each 100 lb of feed. About 50 percent of the bagasse is cellulose. Approximately 75 to 80 percent of this cellulose is solubilized by the microorganisms. Of this 37.5 to 40 lb of cellulose consumed from the initial 100 lb, about 50 percent is used to satisfy the metabolic requirements of the living cells. The remainder is converted to cell mass.

The harvested cells are about 50 percent protein, and the amino acid analysis shows that this protein is high in lysine and other essential amino acids that are usually deficient in vegetable proteins. A comparison of the amino acid pattern of *Cellulomonas* with the ideal amino acid profile recommended by FAO shows that our product compares quite favorably.

Feeding studies on male weanling rats have shown that the limiting amino acid in our cells is l-methionine. When the rats were fed ad libitum or an otherwise adequate but protein-free diet or the same basal diet containing various amounts of these intact cells, they showed definite weight gains above the 20 percent level of supplementation. Rats fed with cells enriched with 0.5 percent l-methionine showed improved growth rates. Rats fed for several weeks at the 70 percent cell level showed none of the toxic responses normally associated with high nucleic acid levels. Prehydrolysis of the cell walls or cell wall rupture by homogenization improved the overall digestibility of the protein product. Other feeding studies on rats, chicks, swine, and cattle are now underway.

The economic feasibility of producing proteins from the cellulosic portion of urban solid waste depends to a large extent on the growth rate of the microorganisms. To improve this aspect of the problem, a study is underway on methods of improving the kinetics of cell growth. Initial results of this study have shown what was known all along, that very few natural processes occur rapidly with a single pure organism but instead proceed by using several organisms, each with a function that hastens the overall process.

In this work it was found that the rate of cell production was being limited by a build-up of cellobiose in the menstrum. This was apparently giving feedback inhibition or allosteric inhibition as it is sometimes called. A second organism was then found that was quite specific for *β glucosidase*. This bacterium, genus *Alcaligenes* and species *Faecalis,* was grown symbiotically with *Cellulomonas.* The end result has been a nearly five-fold increase in growth rates. Surprisingly, the *Alcaligenes* does not propagate itself to a large extent and is found to represent only about 7 to 8 percent of the final cell mass.

A chemical microbial pilot plant was designed and built to produce proteins by this technique and to check our laboratory findings on a larger scale. Considerable operating information is being obtained from this unit. The large unit was built at NASA's Mississippi Test Facility. Since the facility is large, we can check out much more precisely the important economic aspects of our process. Several difficulties have been observed that were not apparent in laboratory research.

One of the most difficult problems encountered in the pilot plant has been the metering of dry solids into the continuous system. Very precise metering is necessary to obtain careful material balances that will help determine the economics of the process.

Difficulty has also been encountered in the large unit, cell concentrations being much smaller than expected. We are obtaining only about 1 g of dry cells per liter of effluent from the fermenter. This is considerably less than the design concentration of 6 to 7 g/liter.

A careful analysis of the cause of the small cell concentrations has led us to believe that the C_1 enzymes are induced and not constitutive as originally presumed. If one examines the growth curves of *Cellulomonas,* they show a distinct log phase of cell growth that does not reach a completely stationary phase as most cells do but instead gradually increases with time.

During the initial alkali pretreatment of waste cellulose, about 20 percent of the original cellulose is solubilized. We have interpreted this information to mean that the cells are feeding on this product during the log phase of cell growth and that only after most of the soluble carbohydrates have been consumed do the C_1 and C_x enzymes become very active. The gradual increase of cell growth during the stationary phase is the result of the gradual induction of the complete enzyme system.

We have finally concluded that the best way to induce fully the C_1 and C_x enzyme system in a continous process is to go to a two-stage fermentation. In this system all the soluble carbohydrates should be consumed in the first fermenter, and the second fermenter should then contain a well-developed cellulase system of enzymes that should lead to utilization of the remainder of the cellulose.

An economic analysis has been projected based on a plant to produce 100 tons of protein product per year for recycle through animals. This analysis shows that the product cost should be competitive with soy bean protein if the cell concentration can be increased to 6 to 7 g/liter and if the two-stage fermentation gives the anticipated growth rates.

PUBLICATIONS

HAN, Y. W., and V. R. SRINIVASIN. Isolation and characterization of a cellulose-utilizing bacterium. *Applied Microbiology*, 16(8):1140–1145, Aug. 1968.

CALLIHAN, C. D., and C. E. DUNLAP. The economics of microbial proteins produced from cellulosic wastes. *Compost Science*, 10(1–2):6–12, Spring–Summer 1969.

DUNLAP, C. E., and C. D. CALLIHAN. Fermentative utilization of sugar cane bagasse. Unpublished data, Louisiana State University, Baton Rouge. [Presented at Meeting, American Society of Sugar Cane Technologists, June 5, 1969.]

HAN, Y. W., H. A. SHUYTEN, JR., and C. D. CALLIHAN. The combined effect of heat and alkali for sterilizing bacterial spore in sugar cane bagasse. Presented at South Central Branch Meeting, American Society for Microbiology, New Orleans, Nov. 21–22, 1969. [24 p.]

HAN, Y. W., and V. R. SRINIVASIN. Purification and characterization of Beta-glucosidase of *Alcaligenes faecalis*. *Journal of Bacteriology*, 100(3):1355–1363, 1969.

Studies on Modifications of Solid Industrial Wastes

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Grant No. EC 00257–02
Funds Awarded: $157,518
Project Period: Feb. 1, 1969 to Jan. 31, 1971

OBJECTIVES: To determine the physical and chemical properties of major process chemical industries' solid wastes and to study modifications of these properties that will permit rehabilitation and beautification of the presently barren land areas covered by deposition of these wastes.

APPROACH: To meet the objectives the following coordinated program is being carried out: (1) Collect and collate the available information on the physical and chemical properties of various solid industrial wastes from chemical process industries to determine common characteristics and variants; choose a typical solid industrial waste for analysis and classification of the physical and chemical constituents and determine their consistency. (2) Study methods and rates of infiltration, percolation, and leaching, under simulated natural conditions, for removal of chemical constituents known to be harmful to desirable vegetation. (3) Investigate modifications of solid industrial wastes by mechanical manipulation and by chemical treatments to alter the "soil" properties so that desirable vegetation can be grown; test optimal modifications in small "flats" in the laboratory and in small plots *in situ*.

Findings: Evaluation and summarization of the accumulated data have shown the exceedingly broad scope of the solid wastes problem. It has been demonstrated that personal solicitation through letters and interviews is very frequently necessary to obtain adequate response, not only from individual industries, but also from national organizations. Significant data reinforce conclusions that the scope of the total solid waste problem in quantity is 7 to 10 times the quantity of municipal solid wastes (frequently quoted as 2 to 1) and that the varied quality of solid wastes necessitates a multifold approach to handling and disposal methods. Too little attention is currently being paid to reclamation values and reuse possibilities of many varieties of solid wastes.

The specific solid waste chosen for initial experimentation arises from Solvay process productions of soda ash (sodium carbonate) utilizing raw materials of limestone and salt. In various localities, large areas of land have been used for deposition of the solid wastes from this chemical process. Removal of soluble salts is slow (many years—20 to 100); rehabilitation is inhibited by the salt content's preventing growth of suitable cover vegetation and by the lack of suitable load-bearing characteristics, which causes settling of structures, noticeable even under reinforced highways. The major conclusions from present experimental studies are as follows: (1) Leaching of the soluble salts is feasible but slow, even if the necessary subsurface drainage system is provided. (2) Vegetation will develop in top soil placed over the waste bed material if proper drainage is maintained so that leaching continues to overcome capillarity.

Research studies are being continued on this waste, and definitive investigations on the chemical and biochemical reactions leading to the so-called coal mine drainage and the leaching of synthetic fertilizing elements from farm lands are being initiated.

PUBLICATIONS

Grove, C. S., Jr., M. L. Kestner, and N. L. Nemerow. Rehabilitation of solid industrial wastes disposal sites. Presented at 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette. May 6–8, 1969. 28 p.

Thermophilic Aerobic Process for Waste Treatment

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Grant No. EC 00268–03
Funds Awarded: $89,738
Project Period: Aug. 1, 1967 to July 31, 1970

Objectives: To study the application of a thermophilic aerobic-digestion process leading to the treatment of organic wastes, particularly ground solid wastes containing 3 to 5 percent garbage solids and primary and waste-activated sewage treatment sludges. To develop a theoretical mathematical model for the process that expresses temperature of the reactor and concentration of the effluent substrate as a function of the concentration, detention time, and oxygen supply rate of the input substrate.

Approach: Ten-liter continuous-flow reactors with provisions for mixing, flow variation, air injection, pH determination, and effluent measurement were used. The effects of temperature and detention time were studied. The reactor effluent was studied by analysis for substrate, cell mass, and carbon-hydrogen-nitrogen content of the washed cells; by photomicrograpy of the cells; and by analysis for COD, effluent gas composition, and dissolved oxygen as close to steady-state conditions as possible. The last phase of this project determined the effect of rapid changes in the reaction mixture temperature on the process.

A mathematical model for the process that expresses production of the effluent substrate as a function of concentration, detention time, and oxygen supply rate of the substrate was developed, initially from theoretical knowledge and, as research progressed, from experimental results. Computer simulation studies were made to guide model development and experimental planning and to indicate the direction of future pilot-plant research.

FINDINGS: Computer simulation studies indicate that the process would be feasible for the treatment of mixtures of organic solid wastes and primary and waste-activated sludges. Sufficient heat would be generated internally in the process to make it self-sustaining at temperatures of 100 to 130 F. The process would have the advantage over other biologic processes of increased reaction rates and increased destruction of organic solids.

The parameters for use in the model have been determined experimentally for simple substrates. The experimental results prove that the advantages claimed are true for simple substrates. Preliminary results from experiments and modeling efforts to determine the effect of rapid changes in reaction mixture temperature on the process indicate the variables (airflow rate and solids content) that have the greatest influence on reaction mixture temperature and that should, therefore, be controlled during process operation.

The process is now ready for field studies at a pilot scale with a mixture of garbage and domestic sewage sludge.

PUBLICATIONS

KAMBHU, K., and J. F. ANDREWS. Aerobic thermophilic process for the biological treatment of wastes—simulation studies. *Journal of the Water Pollution Control Federation*, 41 (5, pt. 2, Research Supplement):R127–R141, May 1960.

KAMBHU, K., and J. F. ANDREWS. Mathematical model for mixed cultures of thermophilic micro-organisms. Presented at 62nd Annual Meeting, American Institute of Chemical Engineers, Washington, Nov. 16–20, 1969.

Use of Domestic Waste Glass for Urban Paving

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Grant No. EC 00329–01
Funds Awarded: $32,653
Project Period: June 1, 1969 to May 31, 1972

OBJECTIVES: To establish that waste glass can be used as an aggregate in bituminous mixtures for street maintenance and to illustrate this potential use as a method of solving urban glass waste disposal problems. To acquire engineering data on bituminous-glass mixtures with respect to suitable gradation ranges for the glass aggregate, proper grade and type of asphalt to be used, and the range of asphalt contents satisfying stability, durability, and workability requirements.

APPROACH: The first of the two project phases consists of laboratory studies to determine the properties of the glass aggregate and bituminous materials that produce suitable paving mixtures. The mixtures investigated include aggregates consisting entirely of glass as well as combinations of conventional mineral aggregates and glass. Also included in this phase is an investigation of the degradation occurring during compaction of bituminous mixtures containing the glass aggregates.

Investgation of the type and grade of bituminous material to be used centers upon adhesion or stripping tests and qualitative evaluation of the mixture's workability. The effect of variations in glass composition upon adhesion is being studied. Specimens are fabricated at several asphalt contents and tested for stability, flow, compression strength, void ratio, and stripping resistance.

Phase two of the study will be a field testing program in which large batches of the bituminous-glass mixture will be mixed and placed in patches or overlays by the city of Rolla, Missouri. Observation during this phase may suggest modifications in the normal placing and compacting procedures that would facilitate placing the bituminous-glass mixture. Various tests will be conducted to compare the glass-containing asphalt with other types of asphalt mixtures.

FINDINGS: Bituminous mixtures satisfying Marshall design criteria recommended by the Asphalt Institute can be designed by use of penetration-grade asphalts and aggregates composed entirely of crushed glass.

Although some degradation of the glass aggregate does occur under laboratory mixing, compacting, and testing conditions, it is not considered to be severe enough to affect pavement performance.

Severe stripping occurs when a bituminous concrete using dense graded glass aggregates and asphalt cement is subjected to a standard laboratory water immersion procedure. By the addition of commercial antistripping agents, this stripping is appreciably reduced.

Using Wastes Formed in Vegetable and Cheese Production

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Grant No. EC 00256–03
Funds Awarded: $142,126
Project Period: Jan. 1, 1967 to June 30, 1970

OBJECTIVES: To study the chemical, nutritional, and microbiological composition of waste materials occurring during the manufacture of processed fruits, cheeses, and vegetables. To investigate the possibility of using these waste products as food or feed for man, farm animals, plants, or soils.

APPROACH: During the first year of the study, the composition of various tomato wastes was determined in the fresh stage as well as in various stages of silage fermentation alone, under varying moisture conditions, and mixed with an equal amount of corn cobs. Ensiling consisted of placing the material in a heavy-duty polyethylene bag and sealing the bag to promote anaerobic fermentation. At various times during the ensiling process samples were analyzed for nitrate, phosphorus, potassium, calcium, magnesium, copper, zinc, and manganese content. The presence of selected vitamins and organic acids was also determined. During the second year, various tomato wastes were placed in 10-ft-high by 6-ft-diameter silos, and after appropriate ensiling times, feeding studies were conducted on sheep to determine the potential of feeding tomato wastes to ruminants. When problems were encountered with the palatability of tomato waste products, studies were conducted to determine the effect of mixing tomato wastes with other plant materials to make them more palatable to ruminants.

During the second and third years of the study fresh, fermented, dried, and fermented-dried wastes were also fed to poultry. The fresh wastes were also applied to different soil types. Depending on the analytical-chemical determinations, nutrients or other substances found in quantity were extracted by various methods.

Cottage cheese and cheddar cheese wheys were studied, and their applicability as human foods was determined. The wheys were concentrated to various solids concentrations by different drying methods. The concentrated wheys were then evaluated for nutritional value, and feeding studies of selected whey concentrations were made on chicks and rats.

In the second and third years of the study attempts were made to use wheys collected and treated by different methods as components of new or modified foods.

FINDINGS: Chemical analyses revealed that tomato wastes, although high in moisture, contain a good proportion of protein. An alkaloid, tomatin, was found in quantities up to ½ percent dry-weight basis in leaves to practically zero in the fully ripe tomatoes. The vines and stems were also high, particularly in SiO_2 with a protein content of 12 to 16 percent dry-weight basis. The ripe fruit waste, on the other hand, contained practically no SiO_2 and had 20 to 22 percent protein dry-weight basis.

Feeding studies with ruminants indicated that ensiled vines and stems are acceptable to sheep provided they are compressed so that anaerobic lactic fermentation develops. Corn cobs and molasses made the silage even more palatable. There was little problem with feeding ripe fruit wastes directly to sheep. The value of these wastes as feed was proportional to their protein content, being better than corn but not equal to alfalfa.

Dried tomato waste could be fed to poultry up to 25 percent of their total feed intake without reducing egg production. When green tomato wastes were fed at higher levels there was a decrease in the cholesterol level of the egg yolk. At this level, however, total egg production was decreased.

A process for totally using tomato cannery waste was developed whereby the waste was compressed, and the presscake containing two-thirds of the solids, 10 percent protein, could be used as cattle feed, and one-third of the solids, 60 percent protein, was precipitated as a tomato protein concentrate. This concentrate can be extracted with acetone to form an 85 percent protein isolate plus a tomato flavor and pigment residue. This tomato protein concentrate has unusually good functional properties and a protein efficiency ratio superior to that of soy.

Application of the wastes to soils indicated that ripe tomato fruit waste had a temporary phytotoxic effect. Green tomato waste could be added directly with little or no phytotoxicity.

The cheese wheys contain approximately 1 percent protein, and this causes problems when the whey is used as a component or an ingredient in processed foods. It was found that the protein of the whey could be stabilized by high-temperature, short-time heating. Whey thus prepared could be used successfully as a milk replacement at levels of 25 to 50 percent in the manufacture of sherbet, ice cream, or pudding. It may be mixed with tomato or other fruit juices as a "fully nutritious drink." When it was fermented with the appropriate microorganisms, acceptable vinegar, beer, and wine were produced.

PUBLICATIONS

BEN-GERA, I., and A. KRAMER. The utilization of food industries wastes. *Advances in Food Research*, 17:77–152, 1969.

Utilization of Bark Waste

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Grant No. EC 00276–02
Funds Awarded: $132,906
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To implement a program in which chemical and physical sciences are coordinated to promote economic use of waste bark and thus decrease environmental pollution caused by present practices. The formation of pellets from waste bark was studied as a model system for the preparation of other molded products such as particle boards and cups. To obtain a detailed chemical description of bark for carbohydrates, polyphenolic polymers, phlobaphenes, tannins, and "bark lignin."

Approach: The preparation of pellets from bark was investigated in a series of experiments controlling species of bark, moisture content, particle size, and hardness of pellet formation. Information obtained from pelleting bark was used to prepare molded or extruded products from bark or bark and plastics combined. Samples of waste bark in various comminuted forms were prepared for experimental use by companies in the forest products, adhesives, or plastics field, or other public agencies.

Chemical composition was determined on natural bark, bark that had been ammoniated to contain 4 percent nitrogen, and bark that had been broken down into smaller particles and molded into pellets. By means of column, thin layer, and gas chromatography, natural bark was analyzed for wax, low-molecular-weight phenolics, and polymeric phenolics in "extractive-free" bark groups. The "extractive-free" bark groups are obtained by sequentially extracting bark with hexane, benzene, ethyl ether, ethyl alcohol, and hot water. An attempt was made to isolate and characterize lignin and cellulose fractions from the "extractive-free" bark group. Conventional methods were used to characterize new compounds and polymers where possible.

Findings: *Physical utilization.*

1. Pelleting trials have been conducted on 15 different species of bark, or mixtures of bark and woody residues. Other variables have included bark moisture content, bark particle size pellet diameter, and degree of pellet densification. Most species of bark pellet easily, but significant problems have been discovered with a few species. The densification factor during pelleting is 2.5 to 3.0; this offers a practical application in transporting bark wastes.

2. Molding of bark has been investigated in several ways: (*a*) Planter blocks compression molded or extruded from bark containing fertilizer and fungicides were used to grow tomatoes and pansies from seed, and then the blocks plus plants were field planted with success. (*b*) Another investigation involved a three-way cooperative study with industry. The Forest Research Laboratory prepared dry comminuted bark, and a lumber company provided the raw bark and financed experimental time on molding machines at a plastics producer. Several types of extruded, sheet-formed, and injection-molded products have been produced, with bark extension of the plastic of about 40 to 60 percent. Preliminary economic analyses appear favorably inclined toward commercial application. (*c*) Douglas fir bark has been prepared for a company interested in extrusion of a fuel log. Trial runs have indicated a log containing largely bark can be formed by this particular process.

3. Samples of bark or bark fractions have been prepared for several companies interested in potential use of bark in their products. In particular, one concern is interested in chemically extracted bark as an extender for wood adhesives. A cooperative project with the Agricultural Engineering Department of Oregon State University has resulted in exploratory research on use of bark in a trickling filter system for disposal of animal wastes.

Chemical utilization. The chemical investigation of bark has involved the areas of: (1) hexane solubles, (2) benzene solubles, (3) bark carbohydrates, and (4) ammoniated bark.

The hexane- and benzene-soluble fractions are mostly of the "vegetable wax" type, and the research has concerned the chemical composition of these waxes. The bark carbohydrate studies have involved isolation procedures. The separation has resulted in fractions containing the polyphenolic polymers, the phlobaphenes, the tannins, the bark lignins, and finally the insoluble carbohydrates.

The "ammoniated bark" has been prepared by treatment of natural bark with gaseous ammonia to a nitrogen content of about 4 percent. For comparison purposes the experimental procedure on this treated bark has been similar to that on "natural bark."

1. *Hexane-soluble wax fraction.* (*a*) Analyses by spectral methods have indicated that this wax contains two long-chain fatty alcohols that may be behenyl (C_{22}) and ligno-

ceryl (C_{24}) esters of ferulic acid. Gas chromatographic methods have been developed to separate these alcohols for analytical purposes. (*b*) Column chromatographic separation of the whole hexane wax shows two bright yellow-green bands that are incompletely resolved. After elution from the column, these bands have been shown by thin-layer chromatography to contain at least 10 components. The main fraction from the thin-layer separation has been further resolved into three components by gas-liquid chromatography. The major fraction from the gas chromatogram was collected and its structure determined by infrared, ultraviolet, and nuclear magnetic resonance spectroscopy. (*c*) Qualitative analyses of the alcohol fraction (neutral fraction) and the acid fraction of the hexane wax were made by gas-liquid chromatography.

2. *Benzene-soluble wax fraction.* Separation of two compounds that appear as yellow bands on column chromatographic separation of the entire benzene wax has been accomplished. These compounds are highly (and pleasantly) aromatic. Resolution of this mixture into their pure compounds is under investigation by both thin-layer chromatography and gas-liquid chromatography.

3. *Bark carbohydrates.* (*a*) The inner bark was collected from a standing Douglas-fir tree 135 years old. (*b*) The inner bark was successively extracted with 80/20::ethanol/water, 2/1::benzene/ethanol, hot water, dilute ammonium oxalate, and acidified sodium chlorite. (*c*) The 80/20::ethanol/water extract (15.4 percent of the inner bark) contained a trace of free glucose, as shown by paper chromatography. (*d*) The 2/1::benzene/ethanol extract (3.0 percent of the inner bark) contained no free sugars, as tested by paper chromatography. (*e*) The water extract (8.6 percent of the inner bark) contained a trace of free glucose, as shown by paper chromatography. Preliminary experiments after acid hydrolysis showed glucose and several amino acids. Color tests also indicated the presence of starch in this fraction. (*f*) The ammonium oxalate extract (3.8 percent of the inner bark) contained no free sugars. After acid hydrolysis the fraction was shown to contain glucose, arabinose, and trace amounts of other sugars. (*g*) The holocellulose (46.2 percent of the inner bark) resulting from delignification with acidified sodium chlorite represented the major part of the carbohydrates of inner bark. Acid hydrolysis and paper chromatography showed glucose, mannose, galactose, arabinose, and xylose. Elemental tests showed no nitrogen, phosphorus, sulfur, or halogens.

Future research on the carbohydrates of Douglas-fir bark will be centered on this important fraction that makes up 40 to 50 percent of the inner bark. The holocellulose will be separated into its component polysaccharides, and their structures and properties will be determined.

This investigation will allow a close comparison between the carbohydrates in Douglas-fir bark and those utilized commercially. Since the inner bark is composed of more than 50 percent carbohydrates (water extract, ammonium oxalate extract, holocellulose), it is conceivable that a commercially useful carbohydrate will be isolated.

4. *Ammoniated bark.* (*a*) Untreated-bark characterization. A large sample of Douglas-fir bark was collected and ground to a size suitable for research investigation. The bark sample had an overall nitrogen content of 0.46 percent nitrogen. The bark was successively extracted with hexane (4.6 percent solubilized), benzene (2.70 percent solubilized), ether (1.81 percent solubilized), 95 percent ethanol (6.38 percent solubilized), and hot water (2.20 percent solubilized). (*b*) A sample of this bark was treated with gaseous ammonia under laboratory-controlled conditions of temperature, moisture content, flow rate, and pressure. The nitrogen content of the treated bark was 4.08 percent. The treated bark was successively extracted with hexane (4.63 percent solubilized), benzene (2.95 percent solubilized), ether (2.21 percent solubilized), 95 percent ethanol (7.13 percent solubilized), and hot water (7.60 percent solubilized). (*c*) A sample of the original untreated bark was ground to pass a 32-mesh screen. The ground bark was treated with gaseous ammonia as in "b." The nitrogen content was 2.34 percent. The treated bark was successively extracted with hexane (4.16 percent solubilized), benzene (3.92 percent solubilized), ether (1.19 per-

cent solubilized), 95 percent ethanol (6.06 percent solubilized), hot water (7.00 percent solubilized). (*d*) Detailed chemical analysis of the bark and the bark fractions is in progress.

PUBLICATIONS

LEHMANN, W. F. Molding compounds from Douglas-fir bark. *Forest Products Journal*, 18(12):47–53, Dec. 1968.

Utilization of Broiler Litter as Animal Feed

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Grant No. EC 00034-02
Funds Awarded: $68,668
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To develop a satisfactory sterilization method to destroy pathogenic organisms in poultry litter and thus convert the litter into a useful product as animal feed. The sterilized litter is being tested for nutritive value, palatability, and possible toxicologic effects. The cattle and sheep used for the feedings are being tested for organoleptic qualities, wholesomeness of meat, and possible take-up of drug or pesticide residues.

APPROACH: Different litter sterilization techniques are being examined, such as autoclaving at 116 C under steam pressure for 30 to 120 min, heating in a forced-draft oven at 100 and 150 C for 4 to 48 hr, fumigating with ethylene oxide, sterilizing with beta propiolactone from periods of 30 min to 24 hr and, finally, piling in deep stacks for 30 to 120 days to encourage normal heating of the litter. Anaerobic organisms are being counted by use of PRAS media. Approximately 150 samples are being used to check for sterility. Litter from sterilization methods proving to be successful are being analyzed for proximate components, true protein, uric acid, Ca, P, NH_3, drugs, and pesticides.

Litter is secured from various producing areas to ensure that representative samples are being obtained. Short- and long-term feeding experiments are being carried out to determine if toxic factors are present. For the short-term experiment, castrated male sheep are fed rations containing 0, 25, 50, and 75 percent sterilized litter for 80 days. The test animals are checked daily for water intake and urine volume, and urine is analyzed for protein, sugar, ketone bodies, bilirubin, crystals, occult blood, and specific gravity. Blood is analyzed for urea and NH_3, total red and white cell counts, and differential white cell count. Rectal temperatures are recorded daily. At the end of the feeding period, the sheep are sacrificed, and a detailed necropsy is made, including the preparation of histologic sections of the kidneys. For long-term studies, breeding ewes are used. They are fed dry-lot for 3 years; control and experimental diets contain 25 and 50 percent replacement. The ewes are bred once a year and are frequently examined as in the short-term experiments.

Nitrogen utilization and energy values are determined. The palatability of the litter for cattle and sheep when feedings are on a free-choice basis is being observed. One group of cattle and one group of sheep are used for meat evaluation trials such as carcass conformation scores, maturity, marbling, final grade, and organoleptic quality. All trials are analyzed by accepted statistical procedure.

FINDINGS: It has been found that heating broiler litter in a forced-draft oven at 150 C for 4 hr or longer is effective in sterilizing the litter. None of the other procedures have been effective.

Autoclaving or treatment with chemical sterilizing agents has had no consistent effect on chemical composition of the litter. The use of dry heat at 100 or 150 C for 4 to 48 hr resulted in about a 20 percent loss in crude protein. The protein level of the sterile product is still, however, very high, about 32 percent, dry basis, which compares favorably with the protein level of many commercial protein supplements for livestock. The pH of unprocessed litter was found to be about 8. Acidifying the litter prior to dry heat processing by the addition of dilute hydrochloric or sulfuric acid to a pH of about 6 resulted in a nitrogen loss of only about 8 percent.

Considerable variation in chemical composition of samples has been obtained from different areas of Virginia, especially for crude protein, ash and gross energy, but all samples have contained substantial nutrient levels. This variation in nutrient level would not preclude the use of poultry litter as animal feed, since certain other feedstuffs on the market also show considerable variation.

The only pesticide residues detected in the poultry litter have been low levels of DDT and its breakdown products. Since DDT had not been used in any of the broiler houses from which the samples were obtained, the residues probably originated from the feed supplied the birds.

In the 80-day feeding experiment, in which sheep were fed diets containing up to 75 percent sterilized broiler litter, no gross toxicologic effects were observed. There were no feed refusals when the ration contained up to 25 percent litter. Feed intakes were depressed at the higher litter levels, especially when the ration contained 75 percent litter. Feeding litter had no consistent effect on various physiologic parameters such as rectal temperature; water intake; urine volume; blood ammonia, blood urea, total red blood cell numbers, and total and differential white blood cells; and urinary pH, specific gravity, glucose, ketones, bilirubin, protein, and occult blood. At slaughter none of the organs showed any gross abnormalities. Studies of histologic sections of brain, lungs, liver, spleen, and kidney indicated that feeding high levels of sterile litter for as long as 80 days did not produce any pathologic effects.

In the long-term experiment with breeding ewes, thus far, feeding up to 50 percent sterile litter has not produced any deleterious effects. Lambing of the ewes is essentially complete and, at this point, it does not appear that litter feeding has affected performance.

PUBLICATIONS

FONTENOT, J. P., R. E. TUCKER, B. W. HARMON, K. G. LIBKE, and W. E. C. MOORE. Effects of feeding different levels of broiler litter to sheep. *Journal of Animal Science*, 30:319, 1970. (Abstract.)

Utilization of Fibrous Wastes as Sources of Nutrients

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Grant No. EC 00274–03
Funds Awarded: $80,555
Project Period: Feb. 1, 1968 to Jan. 31, 1972

OBJECTIVES: To develop a biologic technique for the conversion of natural cellulosic wastes to products that can be utilized as nutrients by animals. Particular emphasis is given to the optimization of biologic systems that can effectively degrade cellulosic wastes and to the evaluation of the degradation products as a source of animal feed.

APPROACH: Anaerobic bacteria are used as hydrolytic agents in batch-, semicontinuous-, and continuous-fermenter systems employing initially either cotton linters or newspaper as substrates. The products from the fermenters, which include volatile fatty acids, soluble carbohydrates, residue, bacterial cells, and protein, are evaluated as nutrients for animals.

Cellulose-utilizing bacteria are isolated from natural habitats of sewage, rumen, and soil and from cellulose enrichment cultures. The effects of pH, temperature, substrate composition and concentration, and other environmental factors on the effective level of cellulolytic activity are determined. The effects of various agents on the synthesis and activity of the cellulose-degrading enzymes produced by the bacteria are being investigated. The development of mutants by means of chemical mutagens is being investigated as a method of increasing the effectiveness of the bacteria.

Apparently, there are controls within the biologic systems that alter the rate and extent of cellulose utilization. A better understanding of the biochemical mechanism of cellulose hydrolysis will allow more effective application in the fermenter system. These controls and mechanisms are being investigated. The co-inoculation of methanogenic and proteolytic bacteria along with the cellulolytic bacteria is being tried as a means of increasing the efficiency and rate of degradation.

The nutritional evaluation of the end products of fermentation is based on the response of animals to diets containing such products. Rats are used as the test animals in initial studies. Diets containing the concentrated culture effluents from the fermentation process are compared with diets containing the untreated cellulosic material and with a positive control diet containing a carbohydrate known to be utilized well by the rat. The nutritive biologic value of the bacterial protein that is synthesized from inorganic nitrogen is being evaluated in similar feeding trials with rats. When sufficient progress has been made to permit operations on a larger scale, the end products will be fed to either sheep or swine in feeding trials.

Findings: Several cellulolytic strains of *Butyrivibrio fibrisolvens*, *Ruminococcus albus*, and *R. flavefaciens* were isolated from the bovine rumen. Two of the new strains of *R. flavefaciens* were compared with known strains isolated by other investigators at Beltsville, Maryland, and Ohio State University. There were no significant differences in the ability of the bacteria to degrade cellulose. There was some similarity among the partially purified hydrolytic enzymes on an immunochemical basis.

Cellulolytic enzyme synthesis in several strains of *R. flavefaciens* and *R. albus* was repressed by moderate levels of cellobiose, as shown by the decrease in clear-zone formation on cellulose-agar roll tubes. These experiments demonstrated a natural control on enzyme production and therefore a limit on the rate of cellulose degradation. There was no inhibition of the hydrolytic enzyme by cellobiose. Attempts to eliminate this repression by means of chemical mutation have not succeeded. Further studies along this line are, however, in process since this is one of the standard techniques used in industrial microbiology to improve efficiency and yield.

An apparent protein-protein interaction has been observed in cultures of *Ruminococcus* that results in the formation of an enzyme complex that degrades cellulose. Two different components diffuse from different colony types on cellulose-agar roll tubes to form a single enzyme complex that degrades cellulose. A new mechanism for cellulose degradation has been postulated that is based on the combination of an affinity factor and a hydrolytic factor to form a complete cellulase that can hydrolyze native cellulose to cellobiose. The previously held hypothesis on the mechanism of cellulose degradation required two separate enzymes for the degradation of native cellulose. This new mechanism has been considered in relation to the general phenomena of resistance, extent, and nature of cellulose hydrolysis. Experiments are being conducted to elucidate this new mechanism further.

Small fermenters (700-ml Kelly infusion bottles) were used to study parameters of fermenter operation. Cotton linters were used as substrate and *Ruminococcus albus* was used as the hydrolytic agent in a semicontinuous operation with a cycle every 3 to 5 days. Fermenter effluents were analyzed for volatile fatty acids, bacterial protein, soluble carbohydrates, and total organic matter. Gas analysis from the fermenter showed considerable hydrogen production. Methanogenic bacteria were added to the system to remove the hydrogen, a possible inhibitor.

PUBLICATIONS

LEATHERWOOD, J. M. Cellulase complex of *Ruminococcus* and a new mechanism for cellulose degradation. *In* Cellulases and their applications. Washington, American Chemical Society, 1969. (Advances in Chemistry Series, 95). p. 53–59.

Wood Waste Reuse in Controlled-Release Pesticides

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Grant No. EC 00319–01
Funds Awarded: $37,437
Project Period: June 1, 1969 to May 31, 1972

OBJECTIVES: To enhance the effectiveness of pesticides by chemically bonding certain pesticides to solid waste so that the pesticide is released slowly over a long period of time by breakdown of the pesticide-solid waste combination. Pulping wastes and screenings, lignin, sawdust, and solid wood waste such as bark are used as the substrates to which the pesticides are chemically bonded and thus an inactive solid waste-pesticide combination is afforded.

APPROACH: A few representative pesticides, such as 2,4–dichlorophenoxyacetic acid (2,4–D); at 2,4,5–trichlorophenoxyacetic acid (2,4,5–T); and 2,4,5–trichlorophenoxybutyric acid (2,4,5–TB), contain a functional group that possesses a replaceable hydrogen. A hydrolyzable ester-type linkage could be formed between the hydroxyl group in the wood waste and the carboxyl group in the pesticide. Release of the pesticide from the solid waste-pesticide combination is being studied in soil under laboratory and field conditions.

FINDINGS: Several methods for the attachment of carboxyl-containing pesticides to wood wastes are being studied and compared. A number of pesticide-solid waste combinations have been prepared in amounts sufficient for testing and analyzed for their pesticide content. Greenhouse experiments to assess the ability of these combinations to control deciduous growth in the presence of conifer seedlings are now underway. Another preliminary series of tests designed to measure the durability of these solid waste combinations in preventing the germination of weed seeds has also been initiated.

Solid Waste Disposal and Bird Hazard to Aircraft

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Grant No. EC 00277–02
Funds Awarded: $77,427
Project Period: June 1, 1968 to May 31, 1971

OBJECTIVES: To study the factors emanating from solid waste disposal by various landfill methods that have significant influence on the kind, the degree, and the daily and seasonal timing of hazard to aircraft through collision with birds. To survey bird populations and movements for 1 year at most of the disposal sites and airports about San Francisco Bay, with particular attention to flight routes to and from the disposal sites near major airports. An intensive analysis is being made of the number of birds and their regularity of travel between major disposal sites on opposite sides of the bay and on either side of particular airports. A less intensive comparison is being made near airports on the rest of the West Coast, and on the Gulf and Atlantic Coasts, in order to evaluate applicability of the findings in the San Francisco Bay area.

Approach: From September 1968 through April 1969, semimonthly surveys of bird populations were made at the major disposal sites and at all airports around San Francisco Bay proper and less frequently at such disposal site-airport combinations as are available near San Pablo and Suisun Bays. Monthly surveys were then made from May through August 1969 at all the disposal sites and airports, and this schedule of population estimates is being largely continued in 1970. Counts are made by observers in ground vehicles and by a small airplane; this permits coverage of areas not accessible by car, and rapid inventory of large areas. Populations thus surveyed include all birds attracted to the disposal sites that could potentially fly through the danger zone near airports going to and from dumps, but most attention is given to gulls, which constitute the major hazard near salt water. Maps of the whole bay area at the scales of 1:24,000 and 1:62,500 showing detailed habitat features and location numerals are used for noting the position and numbers of birds and for showing flight routes.

During the seasons when bird populations reach a high level, several hundred gulls are captured at selected disposal sites and marked with plastic back tags for subsequent identification. A few are marked and relocated with small radio telemetry devices.

As the pattern of bird movements to and from disposal sites and airports in the San Francisco Bay region becomes apparent, the principal investigator is expanding the study by comparing bird habitats and movements at other disposal sites and major airports elsewhere in the country, particularly near the coasts.

Findings: In the San Francisco Bay region, where the intensive field work of this study is concentrated, there were in 1968 and 1969 a total of 7 major airports (4 military, 3 civil) and 13 smaller airfields located within 5 miles of the bay shore or its tributary tidal channels. In the same belt of mostly low-lying lands about the bay there were 37 solid waste disposal sites, 31 of which were found to attract birds in considerable numbers.

From five to seven species of gulls are attracted regularly to disposal sites in this region. Of all factors associated with the disposal operations, the daily cycle of gull movements creates by far the greatest hazard to the safety of aircraft operations at the nearby airports. Starlings, blackbirds of four species, and in some locations, crows, ravens, and occasional herons, vultures, or hawks constitute the remaining species using disposal sites that also contribute to the birdstrike problem because of their size and/or habit of long distance flights, or both.

When on a disposal site, gulls feed almost entirely in the freshly deposited refuse containing significant amounts of garbage, particularly closely around the bulldozers. Most of these gulls do not feed elsewhere than at the refuse, and so it is thought that the food supplied by garbage is a significant factor in supporting the large populations of fall, winter, and spring.

From combined ground and aerial observations, total numbers of gulls in the vicinity of the bay south of the San Francisco and Oakland-Alameda harbor areas were computed at about 80,000 in October and 85,000 in mid-December 1968. Only 53,000 were located in January, 55,000 in March, and these figures dwindled to 16,000 by May and 3,600 at the low point in June 1969 (more than half of these being in one unit at the southeast end of the bay). Early returnees from breeding grounds had increased the total population again to 25,000 by late July.

In the north bay, censuses of gull populations were less nearly complete, but fairly thorough air counts showed 30,000 to 34,000 from early October to mid-February, total numbers declining to 6,300 by late April, 4,300 by late May, and to less than 2,000 in mid-June.

Peak numbers arrived at the core area in various seasons close to 7:30 a.m., at which time bulldozing of refuse was beginning. Departure, however, took place within about 1 to 2 hours before sunset, or in accordance with diminishing light, even though disposal operations had ceased long before. These flights to roosting and feeding areas would present a significant hazard to aircraft if they were across an airport or its approach and takeoff corridors.

The gull population unit north of the Hayward area contains three disposal sites, two of them accommodating a high volume of garbage daily. The Metropolitan Oakland International Airport lies between these two sites, some of the core area activities of gulls taking place within its boundaries. On roostward flights from the Davis St. site large numbers of gulls travel nearly due westward (usually at 100 to 300 feet high) directly across the jet runway 11–29 or its southeast approach. These gulls apparently go to roosts in the middle of or on the western shore of the bay, but tracing them to their destinations has not yet been possible. At the peak of this flight in November 1969, about 4,000 gulls flew within 10 minutes through the airspace normally used by jet aircraft in the last mile of final approach to landing (1 mile from the disposal site). Although this mass exodus is rather unusual, gulls arriving at this core area in the early morning and departing in the afternoon commonly showed densities of 150 to 500 birds per 1,000 ft of flight "front" per 10 minutes, at distances of 1 to 2 miles from the disposal site. Peak hazard times for aircraft close to ground level at Oakland thus coincide with these flights of gulls to and from roosts.

In the entire region, gulls fly from one disposal site to another and to distant reservoirs. On such "commutes" large numbers pass through air traffic patterns at Moffett and Alameda Naval Air Stations, Palo Alto, Oakland, Fremont, and Skysailing Airports, and at Travis Air Force Base. Numbers of gulls noted on our visits to other airports were much lower.

The marking and subsequent recognition of individual gulls have as shown that there is much more shifting from one disposal site to another than was expected from the rather stable numbers present.

This considerable fluctuation of membership in a particular population adds further complication to the problem of altering solid waste disposal methods or locations so as to reduce bird-strike hazards to aircraft. Merely improving one dump, or controlling the birds at it by various alarm, repellent, or poison methods will be no more than a temporary aid. When food is again available and the flocks resting in a core area are not often disturbed, a population buildup through "around the bay" wanderers would take place. Indications are, therefore, that it will be necessary to institute region-wide improvement in solid waste techniques or to carry out intensive and expensive repellent or control methods indefinitely.

In June and September 1969 the principal investigator visited major and medium-sized air terminals on and near the Atlantic coast from Portland, Maine, to Norfolk, Virginia. Discussions with airport staff, and in many cases visits to nearby disposal sites, led to better understanding of the possible influence of solid waste disposal operations on bird presence and movements at the airports. The following three areas bore remarkable resemblance to the situation in the bay region of California: Boston, New York, and Norfolk. In each of these cases, the airports are on or close to bays or tidal marshes—natural highways for gulls—and there are disposal sites handling large volumes of garbage and rubbish within a few miles. Different jurisdictions are also involved in the seeming inability to plan for correcting the situation. At the Logan International Airport, Boston, and at Kennedy, La Guardia, and Newark Airports, operated by the Port of New York Authority, the airport management is both aware of the problem and attempting to discourage birds that constitute hazards. The nearby disposal sites, documented as the focal points of gull activity in the region, are not, however, under their control. The indicated ultimate solution in these areas, and even more so in the San Francisco Bay area, with its 9 counties and more than 50 cities, is regional control of the solid wastes operation.

PUBLICATIONS

COGSWELL, H. L. Gulls and solid waste disposal in the San Francisco Bay area, California. *In* Proceedings: World Conference on Bird Hazards to Aircraft, Queen's University, Kingston, Ontario, Sept. 2-5, 1969. [Ottawa], National Research Council of Canada. [1970].

Microbiology and Acid Production in Sanitary Landfills

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Grant No. EC 00249-03
Funds Awarded: $77,029
Project Period: Jan. 1, 1967 to Dec. 31, 1969

OBJECTIVES: To determine how decomposition in sanitary landfills may be speeded or slowed through the judicious use of nitrogen, phosphorus, and potassium, under varying conditions of moisture, temperature, and compaction. To determine the succession of microorganisms during the decomposition of municipal refuse, the order of occurrence of organic acids and the species of microorganisms responsible for their formation, and the rate and quantity of gas produced per unit of refuse.

APPROACH: Fresh household refuse was placed in simulated landfills consisting of cylinders ranging in size from 12 to 36 in. in diameter and from 4 to 16 ft high. Representative samples of fresh household refuse were ground and analzed for nitrogen, phosphorus, and potassium by using standard methods of analysis. The microorganisms of a large uniform sample of fresh household refuse were isolated and identified. The remainder of the refuse was then placed in a simulated landfill. To determine the successions of microorganisms as decomposition proceeded, subsamples of the decomposing refuse were taken, microbial isolations were made, and the isolates were identified.

Organic acid determinations were made by using gas chromatographic techniques. A search was then made to identify the organisms producing the various acids. An attempt was made to determine the substrate from which the organic acids were formed. Once the growth of various organisms on the various refuse components had been determined, decisions concerning the addition of potassium, nitrogen, and phosphorus to hasten the microbial metabolism were made.

The gases produced in a simulated landfill were analyzed, and the effect of different types of refuse and moisture content of the refuse determined.

FINDINGS: The following fatty acids were produced in refuse decomposition: acetic, propionic, iso-butyric, n-butyric, iso-valeric, n-valeric, iso-caproic, and n-caproic; acetic and n-butyric were the most plentiful. Organisms likely to have been responsible include Clostridia and *E. Coli*. CO_2, N_2, and NH_3. Protein yielded larger acid concentrations than carbohydrates or fats did. Optimum temperature range for acid production was 30 to 55 C. Optimum moisture for acid production was 60 to 80 percent. Better degradation in refuse occurs with 1.86 percent organic nitrogen as N, 0.31 percent phosphorus as P and 0.23 percent potassium as K than at higher or lower values. In general, decomposition of refuse in landfills is related to the level of nitrogen, the nature of nitrogen (organic is better than inorganic), moisture, temperature, and time. Bacilli and

Clostridia appear to be the most common genera in refuse incubated at 25°C and Lactobacilli, bacilli, and Clostridia at 55°C. Identified isolates of bacteria, obtained from incubated refuse, produced fatty acids in media containing glucose or amino acids as the sole source of carbon.

PUBLICATIONS

DOBSON, A. L., H. A. WILSON, and J. C. BURCHINAL. Factors influencing decomposition in sanitary landfills. *Bacteriological Proceedings*, A77. 1965. (Abstract.)

QASIM, S. R., and J. C. BURCHINAL. Leaching of pollutants from refuse beds. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 96 (SA1): 49–58, Feb. 1970.

Sanitary Landfill Investigation

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Grant No. SW 00038–03
Funds Awarded: $87,337
Project Period: June 1, 1962 to May 31, 1966

OBJECTIVES: To identify the groups of microorganisms active in refuse decomposition. To study oxidation conditions of buried refuse and the effects of moisture, temperature, nitrogen, phosphorus, and potassium on refuse decomposition. To investigate gas production and its composition. To obtain basic chemical and bacteriologic data concerning water pollution emanating from solid waste landfills.

APPROACH: To accomplish these objectives, fresh household refuse and material retrieved from landfills were studied in parallel. In addition, the effects of different strip-mine spoils on refuse, either mixed or in layers, were evaluated. Generally, laboratory investigations were done under controlled conditions, various test cylinders being used for simulated landfills. In some cases, sampling pits were constructed in operating landfills at Morgantown, along with observation and sampling wells.

FINDINGS: Sanitary landfills can seriously damage underground water by causing an appreciable increase in hardness, iron, solids, and various forms of nitrogen and sulfur. Methods of limiting gas penetration into the aquifer are desirable. Volatile acids intensify the leaching of fill materials. Large populations of aerobic mesophilic bacteria were found in exterior seepage from the landfills. Coliform bacteria were found in both fresh household refuse and in sanitary landfills.

PUBLICATIONS

DOBSON, A. L., and H. A. WILSON. Refuse decomposition in strip-mine spoils. *Proceedings of the West Virginia Academy of Science*, 35 (Series 64 No. 7–4):59, Jan. 1964.

DOBSON, A. L., H. A. WILSON, and J. C. BURCHINAL. Factors influencing decomposition in sanitary landfills. *Bacteriological Proceedings*, A77. 1965. (Abstract.)

COOK, H. A., D. L. CROMWELL, and H. A. WILSON. Microorganisms in household refuse and seepage water from sanitary landfills. Proceedings of the West Virginia Academy of Science, 39:107–114, 1967.

QASIM, S. R., and J. C. BURCHINAL. Leaching of pollutants from refuse beds. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 96(SA1): 49–58, Feb. 1970.

Special Studies of a Sanitary Landfill

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Grant No. UI–00518–08
Funds Awarded: $191,436
Project Period: Jan. 1, 1960 to Dec. 31, 1968

OBJECTIVES: In the first 3-year period, to study the effects of physical and chemical phenomena on the decomposition rate of organic matter in a landfill and the resulting effect on volume reduction through field and laboratory efforts. During the next 2 years, to continue the initial objectives and add artificial rainfall plus aerated, irrigated, and gas collection test cells. During the final 3-year period, to continue the previous 5 years' work to permit long-term evaluation and quantitative data collection.

APPROACH: Test sanitary landfill cells were constructed at a Los Angeles County Sanitation District disposal site. The field tests considered the influence of moisture, soil admixture, depth of fill, type of soil, aeration, and temperature on degradation of organic matter in sanitary landfill and on fill settlement. At the site, temperature, humidity, and gas composition were measured automatically. The second project period continued the study of the first six cells and added four to investigate the effects of forced aeration, artificial rainfall typical of a humid area, field crop irrigation, and total gas collection and analysis. The final 3–year period continued detailed data collection and evaluation. To ensure maximum control of the study each load of refuse was weighed and categorized.

FINDINGS: During the first 3-year period, the following was observed.

1. Compared with the landfill constructed in the usual anaerobic manner, which uses 4-ft lifts separated by 1-ft-thick earth covers, the initial in-place density of refuse (*a*) was increased by about 20 percent in a similarly constructed landfill through the addition of sufficient water to maintain a moisture content of approximately 40 percent; (*b*) was increased by about 35 percent through the use of an 18-ft lift, the addition of sufficient water to maintain saturation, and the providing of good compaction; (*c*) was approximately the same in the landfill built with continuous admixture of earth plus the addition of sufficient water to maintain a moisture content of approximately 35 percent; (*d*) was increased from about 6 to 35 percent by the particular and varied methods of construction used.

2. The landfill constructed in an anaerobic manner with a total depth of 20 ft provided an initial in-place density from about 5 to 15 percent more than that obtained at the 9-ft depth.

3. Normal compaction procedures used in landfill construction provided initial in-place densities of refuse from about 15 to 50 percent more than the delivered truck density, depending upon the method of construction used.

4. The landfill constructed in an aerobic manner, by using 18-ft lifts and added water, maintained an active composting environment with high temperatures and with settlement rates as much as 3 times that of a corresponding anaerobic landfill, but a fire hazard existed.

5. The 20-ft-deep landfill, regardless of its method of construction, had the greatest shrinkage in the first month following its completion. After the sixth month, the rates of settlement of all the landfills were generally less than 0.05 ft per month.

6. Total settlement within the two landfills arranged for study increased with total depth; in this investigation, doubling the depth resulted in an average increase in total settlement of about 40 percent.

7. The gases produced within the anaerobic landfills consisted chiefly of carbon dioxide and nitrogen. The concentration of

methane depended upon the moisture content and varied from little more than a trace in the landfill constructed without the addition of water to that of a major component (greater than 50 percent) in the saturated landfill. Hydrogen was not present except occasionally in very small amounts.

8. The gases produced within the aerobic landfill consisted chiefly of carbon dioxide and nitrogen. The concentration of oxygen generally did not exceed 10 percent.

9. The production of methane was markedly increased by surface irrigation of a landfill.

10. The gases produced within the four landfills arranged for study diffused laterally and vertically downward into the surrounding ground, as well as upward through the top cover.

11. The initial peak temperature within all landfills was reached within 3 months following the start of construction and occurred at varying depths; no significantly higher temperatures were reached thereafter.

12. The initial temperatures in the aerobic landfill greatly exceeded those in the anaerobic landfills.

13. Grasses, shrubs, and trees were satisfactorily grown on the surface of a landfill.

During the second phase of this project, landfill cells having a depth of approximately 20 ft were constructed and studied. The following was observed.

1. Initial landfill compaction ratios from 2.1 to 2.2, and an in-place density of 1,000 lb/cu yd were achieved for the three test cells A, B, and C. The in-place density for cell D was 634 lb/cu yd.

2. Cell A, receiving the Seattle rainfall equivalent of 184 in. plus an extra 30 in. (for a total of 214 in. of water), exhibited some percolation into the subgrade as evidenced by a 7 percent increase in the moisture of the subgrade over that of undisturbed soil at similar depth. At the close of the project, the differential was 12.5 percent.

3. Cell B, receiving 392 in. of applied irrigation water, exhibited greater percolation into the subgrade as evidenced by a 15 percent increase in moisture content of the subgrade over that of undisturbed soil at similar depth. At the close of the project, the differential was 41 percent.

4. The growth of Bermuda grass was successfuly maintained on an anaerobic landfill with a top earth cover of 2 ft especially prepared to favor turf growth.

5. The greatest settlement (4.25 ft) occurred in aerobic cell C. The two anaerobic cells each settled 2.20 ft.

6. In anaerobic cells A and B, after aging 2 years, the major gas constituents by volume were carbon dioxide and methane in almost equal amounts (nearly 50 percent). Oxygen and nitrogen were present in small, varying amounts.

7. Cell C was aerobically operated, and the gas composition was dependent upon the duration of the blower operation. The gas samples obtained during aeration were characteristically high in nitrogen and oxygen and low in carbon dioxide and methane.

8. The maximum temperature reached in anaerobic cell A was 108 F after 79 days. Over the final 2 years of the more than 4-year study the temperature ranged between 53 and 88 F.

9. The maximum temperature reached in cell B was 120 F after 31 days. Over the final 2 years of the study the temperature ranged between 60 and 90 F. Although intended to be an anaerobic cell, its performance was influenced by the passage of air from aerobic cell C notwithstanding a 5-ft-wide, continuous adobe-shale barrier.

10. The maximum temperature reached in cell C was 193 F after 174 days. Over the final 2 years of the study the temperature ranged between 90 and 164 F. Bottom temperatures reached peaks high enough to destroy thermistors. Smoke emanations with fire were noted on a few occasions. The cell temperature was affected by the aeration cycle.

11. A cell similar in construction to cell A or B but smaller, intended for quantitative studies of gas production, was unsuccessful although constructed with extreme care by professional plastic fabricators. The polyethylene envelope was not able to store gas.

12. The maximum temperature reached in cell D was 117 F after 368 days. Over the final 2 years, the temperature ranged between 67 and 120 F.

13. Seventy-three cu yd of refuse packed into an underground sealed and instrumented steel tank produced 2,027 cu ft of gas, or 27.7 cu ft/cu yd of refuse, over 907 days. Virtually all the gas was produced between the 230th and 600th day.

14. Final examination of the cell materials during the coring operation showed the refuse of aerated cell C to be well decomposed except for plastics and other inerts. In contrast, the refuse of anaerobic cells A and B was easily identifiable.

15. Based on the original cell depth of 20 ft, the volume reduction achieved through aeration amounted to 21.5 percent. The volume reduction achieved in the anaerobic cells was 11.5 percent.

16. Epoxy-coated leads, galvanized pipe, and asphalt-coated steel were found to be inadequate for this type of investigation. All seriously deteriorated or failed because of high temperatures, corrosion, or strain exerted by differential settlement.

PUBLICATIONS

MERZ, R. C., and R. STONE. Landfill settlement rates. *Public Works*, 93(9):103, 106, 210, 212, Sept. 1962.

MERZ, R. C., and R. STONE. Gas production in a sanitary landfill. *Public Works*, 95(2):84–87, 174–175, Feb. 1964.

MERZ, R. C., and R. STONE. Sanitary landfill behavior in an aerobic environment. *Public Works*, 97(1):67, Jan. 1966.

MERZ, R. C., and R. STONE. Progress report on study of percolation through a landfill. *Public Works*, 98 (12): 86, Dec. 1967.

MERZ, R. C. and R. STONE. Quantitative study of gas produced by decomposing refuse. *Public Works*, 99 (11): 86–87, Nov. 1968.

Pollution of Subsurface Water by Sanitary Landfills

Dr. A. A. Fungaroli
Advanced Study Group for Soil, Water & Urban Engineering
Drexel University
Philadelphia, Pennsylvania 19104

Grant No. EC 00162–04
Funds Awarded: $324,268
Project Period: Sept. 1, 1966 to Aug. 31, 1972

OBJECTIVES: To provide criteria for the design of sanitary landfills in given areas and under conditions so as to minimize the possible pollution of subsurface water.

APPROACH: By use of a controlled laboratory sanitary landfill, a controlled field sanitary landfill, and several active landfills, located in southeastern Pennsylvania, models are being developed to describe the behavior of sanitary landfills. The models are being used to predict landfill behavior under various environmental conditions. The specific data being collected are for landfills located in regions underlain by the Wissahicken Schist formation.

The hydraulics of landfills are being determined with respect to the bulk movement of water through them and into underground soils and water bodies. A computer model is being developed to describe the macroscopic functioning of the landfills and the underground flow systems. These models will provide the necessary data to predict bulk movement of leachate through and away from the landfills. Parameter influences on leachate movement are being studied by use of the models. Among the parameters being considered are landfill geometry, refuse characteristics, soil properties, and ground water levels.

The experimental investigations place major emphasis on the character of the pollutants carried by the leachate and on the influence of leachate quantity on concentration of various ions. Because of the complex functioning of landfills, special emphasis is placed on relationships among the various ions present.

The models are being developed so that they can be applied to landfills outside the investigation area. It is expected that final models will be used in the determination of optimum landfill dimensions, soil cover thickness, potential remedial procedures for existing leaching landfills, and associated studies.

Findings: The most advanced portion of this study consists of the data being collected from the laboratory lysimeter. The moisture-routing model for predicting the appearance of leachate has been completed and tested by the lysimeter. The difference between prediction time and leachate appearance is considered minimal. The model is currently being tested on the field installation. If comparison is again favorable, the model will be ready for more general application.

The lysimeter has provided information indicating that the leachate-carrying pollutants begin to move out of a landfill as soon as it is started. Although the initial quantity of leachate generation is low for landfills with low moisture contents at placement, it cannot be considered negligible. Further, ion concentrations in the initial leachate have been shown to be substantial.

The lysimeter results have shown that once the refuse system reaches field capacity, the total amount of pollutants removed increases rapidly. The particular parameters evaluated are:

Liquid: pH, hardness, dissolved oxygen, phosphate, chloride, sodium, suspended solids, total residue (total dissolved solids), nitrogen (ammonia, organic), nitrate, chemical oxygen demand, biochemical oxygen demand, iron, zinc, copper, nickel, and sulfate.

Gas: carbon dioxide, oxygen, nitrogen, methane, hydrogen sulfide, and carbon monoxide.

Temperature data gathered in the lysimeter indicate that the system was initially aerobic and reached temperature levels as high as 150 F shortly after activation. A comparison of lysimeter temperature data and data gathered from the field installation indicates that initial temperature behavior may be a function of unit weight of refuse placement. In the field, where the refuse was placed at higher unit weight, temperatures did not reach the lysimeter levels and the refuse was anaerobic almost immediately.

Publications

Remson, I., G. H. Emrich, A. A. Fungaroli, and A. W. Lawrence. Pollution of subsurface water by sanitary landfill. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, University School, Milwaukee, July 24–28, 1967. Conference Preprint No. B–2.

Remson, I., A. A. Fungaroli, and A. W. Lawrence. Water movement in an unsaturated landfill. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 94(SA2):307–317, Apr. 1968.

Sowers, G. F. Foundation problems in sanitary landfills. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 94(SA1):103–116, Feb. 1968. Discussion. Fungaroli, A. A., and R. L. Steiner. Foundation problems in sanitary landfills. *Journal of the Sanitary Engineering Division*, American Society of Civil Engineers, 94(SA4):764–766, Aug. 1968.

Steiner, R. L., and A. A. Fungaroli. Construction of laboratory and field facilities for the investigation of leaching from sanitary landfills. *In* Proceedings; Second Mid-Atlantic Industrial Waste Conference, Philadelphia, Nov. 18–20, 1968. Drexel Institute of Technology, 1969. p. 301–324.

Suffet, I., A. A. Fungaroli, R. J. Schoenberger, and S. Levy. Specific ion electrodes analysis of wastewaters from solid waste disposal. *In* Proceedings; Third Mid-Atlantic Industrial Waste Conference, College Park, Md., Nov. 12–14, 1969. University of Maryland. p. 279–303.

Preventing Landfill Leachate Contamination of Waters

Mr. Eddie J. Wren
Department of Environmental Science
Gulf South Research Institute
Baton Rouge, Louisiana 70808

Grant No. EC 00393-01
Funds Awarded: $56,550
Project Period: Aug. 1, 1969 to July 31, 1971

Objectives: To develop sealant liner materials that will prevent the escape of leachates to the surrounding soil and ground waters when the leachates are applied to sanitary landfills. The use of low-cost, readily available waste byproducts as liners is being evaluated.

Approach: A direct-contact survey is being made of industries concerning their byproduct waste to determine the location and quantities of these potential barrier materials. Some of the criteria used for selection of materials are particle and liquid permeability, inertness, availability, cost, and handling and storage problems. Laboratory test cells have been constructed for testing and evaluating the effectiveness of the selected barrier products by use of a glass tube and by observation of cell activities such as moisture gradient and volumetric changes. Leakage through the cell liner material into the soil layer beneath will be monitored by frequent analysis of the soil beneath the liner with a water-soluble dye and a radioactive tracer placed in the cell above the sealer.

Laboratory results will lead to investigations on a small-scale outdoor sanitary landfill where water levels and drainage patterns are well established. A liner material indicated as suitable by laboratory studies will be used to set up field cells. A water-soluble fluorescent dye, not radioisotopes, will be added during the filling operation in order to check for leaching in these field studies. Other parameters for checking leachate loss as well as contamination of ground water by the barrier material, will be pH, alkalinity, suspended solids, nitrogen compounds, COD, BOD, DO, sulfates, sodium, chlorides, TDS, hardness, phosphates, nitrate, calcium, magnesium, iron, and infrared scanning.

Findings: The initial screening of some 29 industrial products (waste, in most instances) that seemed to be likely candidates for soil sealants resulted in 18 of these being retained and tested for permeability. All these products are nonbiodegradable.

The nonpermeable materials will be tested in laboratory cells simulating elemental cores of field landfills.

Stabilizing Sanitary Landfills by Injection Grouting

Dr. Lyle K. Moulton
Department of Civil Engineering
West Virginia University
Morgantown, West Virginia 26506

Grant No. EC 00016-01
Funds Awarded: $38,929
Project Period: Feb. 1, 1970 to Jan. 31, 1973

Objectives: To determine the effectiveness of injection grouting of waste material in accelerating the stabilization of sanitary landfills so that landfill sites can be reclaimed and put to use in the shortest possible time. It is anticipated that grouted landfills can be used not only for parks and playgrounds but also for industrial, commercial, and residential development.

Approach: Various grouting materials with emphasis on fly ash, bottom ash, and other wastes with cementaceous characteristics will be studied to determine their effect on landfill stabilization. Different grout-refuse combinations are being studied to determine their effect on landfill strength and settlement characteristics. The influence of various types of grouts on biological decomposition and long-term landfill stabilization is also being determined.

Landfill settlement characteristics will be studied in the laboratory by use of large consolidometers whereby refuse cells will be loaded to simulate various applied surface loads. Time settlement data will be recorded and leachate analyses performed. The influence of grouting on the strength of compacted refuse will be evaluated by use of a triaxial compression apparatus. Samples of refuse will be compacted into cylindrical molds 6 in. in diameter and 12 in. long and grouted. At various intervals the samples will be tested for strength and then microbiologically analyzed to determine the effect of grouting on biological decomposition.

After the laboratory tests, a limited field evaluation will be performed. Two small refuse cells, about 50 cu ft, will be constructed. One is grouted and one is not. Settlement records will be kept and periodic sampling and analyses of leachate and gases will be performed to evaluate the effect of grouting.

Findings: This grant was awarded February 1, 1970, and findings are not yet available.

Thermophilic Metabolism in Solid Substrates

Dr. Marvin E. Stephenson
Department of Civil Engineering
Michigan State University
East Lansing, Michigan 90007

Grant No. EC 00292–02
Funds Awarded: $72,440
Project Period: June 1, 1968 to May 31, 1971

Objectives: To investigate the principal variables affecting the decomposition of biodegradable solid waste by thermophilic aerobic organisms. Both macro and micro components of the decomposition products are measured by using a laboratory model of the reacting system. The study also provides for the development or evaluation, or both, of analytical methodology necessary for the physical and chemical characterization of constituents related to the decomposing material.

Approach: Laboratory studies are being carried out in a replicate series of 1.5-cu-ft-capacity reactors housed in a controlled-temperature module. Suitable analytical methods and monitoring systems have been instituted to assay the reactants and products continuously during the decomposition process.

The samples of municipal refuse used in this project are collected locally, sorted to remove glass and metal materials, and then pulverized to particle sizes of less than 1/4 inch. During the decomposition process, the influent and exhaust gas streams are monitored chromatographically on a semicontinuous basis. Samples of the decomposing mass are removed periodically and analyzed for organic and inorganic carbon, organic nitrogen, and moisture content. Analytical determinations, including pH and nitrate-nitrogen, are also performed on the liquid fraction of the sample. The environmental variables that are controlled or otherwise adjusted are temperature, moisture content, and air supply.

Findings: Studies of the assay of solid municipal refuse indicated that a measure of total organic carbon, rather than the separation of the organic carbon complex into constituent series such as holocellulose, crude starch, and reducing sugars and lipids, provided a more satisfactory estimate of reactive carbon. Accordingly a wet-combustion method for organic and inorganic carbon was developed to permit the analysis of large (1– to 10–g) samples.

Preliminary results of the project indicate that the organic carbon-nitrogen ratio is a useful parameter of biologic stability and suggest its employment in conventional sanitary landfill practices. Generally, biological activities resulting in carbon and nitrogen losses from the decomposing mass were completed within 30 days of the initiation of the experiment at all levels of moisture content and temperature set. In certain cases significant formation of nitrate-nitrogen in the leachate (<700 mg/liter) were recorded.

The practical indications of this study suggest the possibility of certain changes in present sanitary landfill practices.

1. Comminution of the refuse before deposition would increase in-place densities and provide a more suitable substrate for the promotion of biologic activity necessary for rapid stabilization of the fill material.

2. Further consideration of the development of economical methods of landfill aeration and moisture control should be instituted.

3. Practical methods for the establishment of lower carbon-nitrogen ratios in raw refuse would increase the rate of aerobic decomposition of this material.

4. Formation of significant amounts of nitrate-nitrogen during the stabilization process should be considered, and methods should be instituted for the control of liquid passing through the fill.

Marine Disposal of Fine-Grained Waste Solids

Dr. M. Grant Gross
Marine Sciences Research Center
State University of New York
Stony Brook, New York 11790

Grant No. EC 00388–01
Funds Awarded: $89,885
Project Period: Feb. 1, 1970 to Jan. 31, 1972

OBJECTIVES: To study the fine-grained waste solids that constitute about 95 percent of all waste presently dumped in the coastal waters of the New York Bight and in the estuarine waters of Long Island Sound. The long- and short-term physical and chemical effects of these wastes on the ocean water and ocean bottom near the disposal site are being determined.

APPROACH: A detailed study is being made on source, physical, chemical, and mineral composition of the fine-grained wastes prior to dumping. The selected disposal site is being studied for mixing of other types of sedimentary materials, for physical and biological processes in changing the characteristics of the original wastes, and for the effects of currents and other processes on the final distribution and amount of material deposited. Individual waste disposal operations are being investigated by pumping water, down current from the disposal operation, through an instrumental chamber where salinity, depth of sample intake, light transmission, dissolved oxygen, pH, and chlorophyll are measured.

FINDINGS: This grant was awarded on Feb. 1, 1970, and findings are not yet available.

Pipe Transport of Domestic Solid Waste

Dr. Iraj Zandi
Towne School of Civil and Mechanical Engineering
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Grant No. EC–00259–04
Funds Awarded: $184,234
Project Period: Sept. 1, 1966 to Aug. 31, 1970

OBJECTIVES: To examine the applicability of the technology of bulk solid transport in pipelines to the collection, removal, and treatment of municipal solid wastes.

APPROACH: Various concentrations and sizes of ground solid waste were transported, under pressure, through different size pipes. Optimum particle size and concentration were determined with respect to both the engineering and economic aspects.

The stochastic processes governing the generation of solid wastes were determined, and their implications on the design of a pipe system evaluated. The cost of pipeline collection of solid waste was evaluated with respect to many factors including population density, size of collection area, distance of transport and type of disposal. Domestic solid waste services were economically evaluated, and analytical economic decision models for solid waste systems were constructed to allow meaningful comparisons of pipe systems and conventional systems.

From the outset it was recognized that for pipeline collection and removal to be considered a viable solution and an attractive alternative tool for management of solid waste, the following four distinctly different questions need to be answered.

1. Is the collection and removal of solid waste via pipeline technologically feasible?
2. If "solid waste pipeline" is technologically feasible, then how does it economically compare with the present truck collection system?
3. If "solid waste pipeline" is technologically feasible and economically attractive, then what method of treatment and disposal should be used?
4. What sociopolitical implications may be expected? What governmental instrument is required to implement this new technology? What would happen to present labor force when solid waste collection and removal becomes automatic?

Most efforts were directed toward answering the first two questions in the first 3½ years of the project. Only in the last year was attention given to the third question.

FINDINGS: In regard to the first question, on the basis of laboratory experimentation, analysis of the data, and field observations, it is concluded that with present technology both pneumatic and slurry transport of domestic solid waste is feasible. As far as slurry transport is concerned it has been established experimentally that municipal solid wastes can be presized by presently available shredding equipment to render them suitable for slurry transport. It was also established that slurries up to 12 percent solid wastes (paper, cans, glass, etc.) can be pumped readily. Pressure loss data were collected for different combinations of pipe diameter, mean velocity, and slurry concentration. A prediction equation was found that permitst he prediction of pressure losses with reasonable accuracy. Based on information obtained so far, the details of which are reported in the publications listed, one may conclude that the goals of the project in regard to laboratory experimentation on pressurized solid waste pipeline have been achieved. The next logical step in the study of pipeline under pressure seems to be a pilot study in the form of a demonstration project. Not much useful information more than what is presently available for *pressure* solid waste pipeline can be obtained in the laboratory.

In regard to economical comparison, two separate decisions had to be made: (1) What would be the level of services, that is, fully automatic (all pipeline, pneumo-slurry system) or semi-automatic (truck-pipeline combination)? (2) What type of community would be selected for comparison? In order to obtain conclusive information it was decided to select two extreme types of communities, one a core of a large metropolitan area (center city of Philadelphia) and another a residential, essentially a bedroom, community (Radnor, Pennsylvania, population 30,000), and provide fully automatic services with access at each point of solid waste generation. In addition, it was decided to assume no new technologic innovations. All equipment required could be obtained on the market. A detailed, conservative economic analysis found the following. (1) For center city of Philadelphia the pneumo-slurry (combination of pneumatic and slurry pipeline) system would be less expensive than truck collection over a period of 50 years, if solid waste has to be transported a distance of more than 50 miles. (The city of Philadelphia is investigating the possibility of transporting its solid waste much further.) (2) For Radnor the fully automated pneumo-slurry system that originates from each house would cost considerably more than present truck collection (slightly more than triple). If, however, a point of entry should be provided for a group of houses, say each four houses, the cost would compare favorably with truck collection. In the economic study all components of the cost, that is, installation, operation, maintenance, and amortization are included. Intentionally all calculations are biased in favor of truck collection in order to establish the real economy of pipeline collection and removal.

In regard to the third question the construction of an experimental facility is near completion for investigating the possibility of using pipeline as a biological reactor to treat the solid waste during conveyance.

PUBLICATIONS

ZANDI, I. Solid waste pipeline. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, University School, Milwaukee, July 24–28, 1967. Conference Preprint No. D–4. 3 p.

ZANDI, I. Collection and removal of municipal solid wastes by pneumo-slurry system. *Compost Science,* 9(2):7–11, Summer 1968.

ZANDI, I., and G. GOVATOS. Pipeline transport of solid waste. *In* I. Zandi, ed. Advances in solid-liquid flow in pipes and its applications. New York, Pergamon Press. (In press.)

ZANDI, I. Pipeline collection and removal of solid waste. Presented at Engineering Foundation Research Conference, Solid Waste Research and Development, II. Beaver Dam, Wis., July 22–26, 1968. Conference Preprint No. A–2.

ZANDI, I., and J. A. HAYDEN. Are pipelines the answer to waste collection dilemma? *Environmental Science and Technology,* 3(9):812–819, Sept. 1969.

YEN, J. G., and I. ZANDI. Transport of slurries in heterogeneous regime. Presented at Annual Meeting, Society of Mining Engineers, Washington, Feb. 16–20, 1969. Conference Preprint No. 69–B–70. 28 p.

HAYDEN, J. A., P. SEIDENSTAT, and I. ZANDI. Solid waste generation and cost in Center City Philadelphia. *Journal of the Sanitary Engineering Division,* American Society of Civil Engineers. (In press.)

HAYDEN, J. A. Slurry flow—solids transport for the future. *Pennsylvania Triangle,* 57(2):22–26, Nov. 1969.

SECTION II

RESEARCH GRANT PROJECTS STATE AND PRINCIPAL INVESTIGATORS

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RESEARCH GRANT PROJECTS
STATE AND PRINCIPAL INVESTIGATORS *

State	Status	Principal Investigator	Page
Alabama (1)	(T)	Scarsbrook, Clarence E.	4
Alaska (0)			
Arizona (0)			
California (15)	(T)	Anderson, John R.	52
	(A)	Cogswell, Howard L.	102
	(A)	Darley, Ellis F.	84
	(T)	Ecke, Dean H.	50
	(A)	Golueke, Clarence G.	60
	(T)	Hart, Samuel A.	15
	(T)	Hart, Samuel A.	29
	(A)	Hoffman, Donald A.	69
	(T)	Mercer, Walter A.	3
	(T)	Merz, Robert C.	107
	(A)	Oswald, William J.	85
	(A)	Rose, Walter A.	11
	(A)	Snyder, William C.	66
	(T)	Stephens, Edgar R.	24
	(T)	Stewart, George F.	14
Colorado (3)	(A)	Lindsay, Willard L.	12
	(A)	Miller, Byron F.	72
	(A)	Updegraff, David M.	78
Connecticut (0)			
Delaware (0)			
Florida (5)	(T)	Block, Seymour S.	71
	(A)	Hortenstine, Charles C.	8
	(T)	Knuth, David T.	5
	(T)	Long, Sterling K.	70
	(A)	Susag, Russell H.	65
Georgia (1)	(T)	Spradlin, Bobby C.	54
Hawaii (0)			
Idaho (0)			
Illinois (6)	(A)	Bryant, Marvin C.	74
	(T)	Bugher, Robert D.	13
	(T)	Charnes, Abraham	56
	(T)	Day, Donald L.	25
	(A)	Pfeffer, John T.	88
	(A)	Sheaffer, John R.	63
Indiana (2)	(T)	Bloodgood, Don E.	58
	(T)	Dale, Alvin C.	19
Iowa (2)	(T)	Hazen, Thamon E.	23
	(A)	Miner, J. Ronald	30
Kansas (1)	(T)	McKinney, Ross E.	15
Kentucky (0)			
Louisiana (3)	(A)	Callihan, Clayton D.	90
	(T)	Wren, Eddie J.	72
	(A)	Wren, Eddie J.	111
Maine (0)			
Maryland (3)	(A)	Kramer, Amihud	95
	(T)	Krusé, Cornelius W.	57
	(T)	Liebman, Jon C.	55
Massachusetts (4)	(T)	First, Melvin W.	43
	(A)	Sarofim, Adel F.	47
	(T)	Silverman, Leslie	38
	(A)	Wilson, David G.	89
Michigan (3)	(A)	Boettner, Edward A.	45
	(A)	Gray, Donald H.	80
	(A)	Stephenson, Marvin E.	112
Minnesota (3)	(T)	Bond, Richard G.	36
	(A)	Bond, Richard G.	39
	(A)	Diesch, Stanley L.	35
Mississippi (0)			
Missouri (1)	(A)	Malisch, Ward R.	94
Montana (0)			
Nebraska (0)			
Nevada (0)			
New Hampshire (1)	(A)	Grethlein, Hans E.	82
New Jersey (1)	(T)	Besley, Harry E.	27
New Mexico (0)			
New York (8)	(A)	Gross, M. Grant	113
	(A)	Grove, Cornelius S.	92
	(A)	Heimburg, Richard W.	49
	(A)	Jeris, John S.	8
	(A)	Kaiser, Elmer R.	42
	(T)	Kaiser, Elmer R.	46
	(T)	Kaiser, Elmer R.	68
	(T)	Shuster, William W.	72
North Carolina (4)	(T)	Axtell, Richard C.	51
	(A)	Galler, William S.	6
	(A)	Hill, Charles H.	87
	(A)	Leatherwood, James M.	100
North Dakota (0)			
Ohio (3)	(A)	Miller, Paul D.	48
	(T)	Taiganides, E. Paul	16
	(T)	Taiganides, E. Paul	21
Oklahoma (0)			
Oregon (3)	(A)	Currier, Raymond A.	96
	(A)	Freed, Virgil H.	76
	(A)	Klein, Donald A.	83
Pennsylvania (5)	(A)	Fungaroli, A. Alexander	109
	(A)	Morgan, Peter E. D.	77
	(T)	Purdom, P. Walton	41
	(A)	Thygeson, John R.	34
	(A)	Zandi, Iraj	114
Rhode Island (0)			
South Carolina (2)	(A)	Andrews, John F.	93
	(A)	Hulbert, Samuel F.	17
South Dakota (1)	(T)	Berry, Edward C.	27
Tennessee (0)			
Texas (2)	(A)	Howes, James R.	31
	(A)	Myrick, H. Nugent	16
Utah (0)			
Vermont (0)			
Virginia (2)	(A)	Fontenot, Joseph P.	99
	(A)	Kelly, James L.	87
Washington (1)	(A)	Allan, G. Graham	102
West Virginia (5)	(A)	Bailie, Richard C.	81
	(A)	Burchinal, Jerry C.	40
	(T)	Burchinal, Jerry C.	105
	(T)	Burchinal, Jerry C.	106
	(A)	Moulton, Lyle K.	111
Wisconsin (1)	(T)	Witzel, Stanley A.	18
Wyoming (0)			

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* See page 131 for complete listing of research and training grant principal investigators.

(T) Terminated } as of March 31, 1970.
(A) Active }

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SECTION III

TRAINING GRANTS

Dr. William W. Shuster
Department of Civil Engineering
Rennselaer Polytechnic Institute
Troy, New York 12181

Grant No. EC 00005–03
Funds Awarded: $131,088
Project Period: July 1, 1967 to June 30, 1972

PROGRAM: This training program establishes an area of specialization, primarily at the M.S. level, in solid waste disposal within the existing programs in environmental engineering. It is aimed at providing personnel trained to assume responsibilities in the supervision, planning, and administration of solid waste management facilities. The study plan for each student is arranged by the student advisor in consultation with the student. Course requirements are flexible, and every effort is made to satisfy the interests and objectives of the candidate consistent with his background and degree of preparation.

Courses initiated under this grant and required of the students participating in this program include one entitled Solid Wastes and one entitled Solid Wastes Laboratory. The Solid Wastes course deals with the preparation of refuse for collection, costs of collection, collection methods and equipment, special refuse problems, disposal and treatment methods, and diseases associated with garbage and refuse. The Solid Wastes Laboratory course covers experiments in solid wastes disposal, techniques for sampling and methods of analysis of solid wastes, chemical and physical changes in composting, leach studies, methods of odor control, and landfill and incineration procedures. Other courses, including Unit Processes, Atmospheric Pollution, and Planning for Waste Disposal and Pollution Abatement, cover subjects related to solid waste management.

A thesis or project is required of candidates for a degree in solid wastes. The thesis or project is expected to be related to solid waste management.

To date, 11 students have completed solid waste courses and 6 have been supported by traineeships.

Dr. P. Walton Purdom
Center for Study of the Environment
Drexel University
Philadelphia, Pennsylvania 19104

Grant No. EC 00006–04
Funds Awarded: $176,789
Project Period: July 1, 1966 to June 30, 1971

PROGRAM: This program provides professional education at the masters level for students concerned with the solution of problems associated with solid wastes. The instructional plan produces graduates equipped to manage the local government units that collect and dispose of solid wastes, to organize and administer State and Federal programs for the promotion of acceptable solid waste collection and disposal practices, and to staff other agencies and consulting engineering offices.

The educational program is designed to cover in depth the characteristics of wastes, systems for collection and disposal, theories that form the basis of design of disposal facilities, pertinent management techniques, and the relationships of solid wastes to other environmental problems. Faculty members from the various engineering and science departments participate in this program. On the successful completion of course requirements, participating students receive a master's degree in environmental engineering, science, or civil engineering, depending upon the electives selected and prior education.

Specific courses directly related to solid waste management being offered are: Solid

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Waste Analysis, Solid Waste Systems, Combustion Theory, Incinerator Design, and Environmental Systems Analysis. Other courses offered that have some relationship to solid waste management practices include air pollution, water pollution, and microbiology.

To date, 18 students have been supported by solid waste traineeships. Five of the traineeship-supported students are currently enrolled in graduate programs at Drexel.

Dr. Russell H. Susag
Department of Environmental Engineering
University of Florida
Gainesville, Florida 32601

Grant No. EC 00007–03
Funds Awarded: $131,094
Project Period: July 1, 1967 to June 30, 1972

PROGRAM: This program is designed to provide training of field personnel for design and operation of solid waste programs as well as training of research personnel for the development of basic data needed to design well-functioning solid waste management systems. The board of regents has given the university the responsibility to provide technical assistance to city, county, and regional planning agencies; health departments; governmental units; private companies; and individuals. Through the training program, a reservoir of trained personnel will be developed to meet these needs.

It is anticipated that the solid waste trainees will be from the engineering and life sciences disciplines. They will be supported at the M.S. level and major in environmental engineering with a specialization in solid waste management with thesis or special problem work in solid waste research.

Special problem courses and two specific solid waste courses are offered. One course entitled Solid Wastes covers the following subject areas: quantities and characteristics of municipal refuse; collection methods, equipment, and costs; refuse disposal practices; and regional planning and management. To date this course has been offered six times with a total enrollment of 52 students. The other course, Analysis of Solid Wastes has been recently offered with an enrollment of three students. Subject areas covered in this course include: physical and chemical analysis of refuse, calorific value, organic content, biodegradability, oxygen and nitrogen requirements, and identification of flora and fauna associated with composting. A third course offering, Design of Solid Waste Management Systems, is being developed. Three students have been supported by solid waste traineeships to date.

Prof. Eugene A. Glysson
Civil Engineering Department
University of Michigan
Ann Arbor, Michigan 48104

Grant No. EC 00008–04
Funds Awarded: $144,857
Project Period: July 1, 1966 to June 30, 1971

PROGRAM: This solid waste training program is designed to attract and train professional personnel who will be better able to apply up-to-date knowledge needed to manage solid waste material properly. The program, administered through the civil engineering department, includes participation from other disciplines such as the environmental health department of the school of public health to provide for an interdisciplinary approach to the solution of solid waste management problems. Students enrolled in the courses come from the college of engineering and the school of public health as well as the school of natural resources.

Two solid waste courses are offered. One, entitled Solid Wastes Engineering, deals with the engineering and design of methods for collection and disposal of the solid wastes of urban communities and the related effects of such collection and disposal on the environment. The other course, Special Problems in Solid Wastes Engineering, covers the application of principles presented in the Solid Waste Engineering course to engineering and environmental health problems in the collection and disposal of solid wastes. Comprehensive analyses and reports are assigned on an individual student basis. Typical special problems include studies related to refuse collection, refuse characteristics, incinerator emissions, landfill stability, incinerator quench water characteristics, and regional solid waste management.

To date the Solid Waste Engineering course has been elected by 54 students over a 6-year period. The Special Problems in Solid Waste Engineering course has been elected by 26 students over the last 4 years. There has been a total of 16 graduates from this program, 9 being supported by this training grant.

Professor Raul Zaltzman
Department of Civil Engineering
West Virginia University
Morgantown, West Virginia

Grant No. EC 00009–03
Funds Awarded: $181,854
Project Period: Jan. 1, 1967 to June 30, 1972

PROGRAM: One purpose of this program is to provide the student with an understanding of the needed design engineering aspects both of existing methods of solid waste management and of methods that are relatively new in application. Another purpose is to introduce improved design criteria and disposal methods that will optimize current operations and provide for adequate disposal of solid wastes resulting from other waste treatment systems.

Three courses are offered by the civil engineering program dealing with solid waste management problems; two of them deal exclusively with solid wastes and the third offers the students an opportunity to integrate the information gained throughout their study program in one major interdisciplinary exercise of total environmental planning. This last course is conducted by the solid waste management and the urban transportation staff with assistance of most of the civil engineering staff on consulting and guest lecture basis. Two other courses, Design of Dynamic Material Systems and Design of Solids Handling Systems, offered by the Departments of Industrial Engineering and Chemical Engineering, respectively, include various aspects of solid waste management as the major portion of the subject matter. The Elements of Solid Waste Management course offered by the Civil Engineering Department covers basic solid waste material, including the study of traditional patterns and problems of solid waste storage, transport, and disposal; a discussion of field evaluation techniques for existing systems and facilities; an examination of engineering alternatives with appropriate consideration for air pollution control and land reclamation; analytical approaches to recovery, conversion, and reuse of materials; and the application of systems analysis concepts to solid wastes handling and disposal systems. Sixty-two students have completed this course through the fall of 1969. The other course offered by the Civil Engineering Department related to solid waste management is Municipal and Industrial Design of Solid Wastes Disposal Operations. This course includes a comprehensive study and review of design criteria for the existing methods and equipment used for the disposal of solid wastes generated by industry and municipalities. The operations studied are subdivided into those accomplishing on-site preparation, volume and density modification, and salvage or reclamation (or both) of ferrous and nonferrous metals and other marketable materials. Also included are studies of the storage and handling practices and equipment involved in these operations. This course is being offered during the spring of 1970 for the third time with a total enrollment of 29 students for this lapse. In addition to the courses offered, 48 guest speakers have presented their views of solid waste management practices to interested students and faculty. The guest speakers have come from private industry, governmental agencies, and other universities.

With the assistance of this grant, 12 students have been directly supported, and 4 others have received partial support through assistantships. There are 11 students currently enrolled in a graduate study program with emphasis on solid waste management; of these, 5 are being supported with traineeships provided by this grant and 1 is receiving partial support.

Dr. Joseph F. Malina, Jr.
Department of Civil Engineering
The University of Texas
Austin, Texas 78712

Grant No. EC 00010–04
Funds Awarded: $235,313
Project Period: July 1, 1966 to June 30, 1971

PROGRAM: This training grant has provided a basis for the development of an environmental health engineering program with special emphasis on solid waste management. A multidisciplinary program with specific emphasis on the application of new engineering principles and processes to the solution of solid waste problems, as well as an awareness of the significance of proper planning management and sociological considerations, particularly in the case of municipal solid waste systems, has evolved. This program includes the training of graduate students by course work and research to solve real problems, the development of a competent health-related teaching and research training program, and the opportunity for both faculty and students to study new approaches to the disposal of solid wastes resulting from municipal and industrial activities. Participation of students and faculty of the Chemical Engineering Department is providing the means for the exchange of information related to the development of new processes or to the application of existing processes to systems of recycling components of the refuse or to disposal systems.

The objectives of this program are being satisfied by formal courses, special seminars, and particular research projects that deal with a broad spectrum of solid waste management, collection, and disposal problems. Trainees sponsored under the auspices of this project at present are all master of science candidates who are pursuing program-prescribed course work in environmental health or in civil or chemical engineering. A thesis related to solids problems is required of each trainee.

The course initiated under this grant, entitled solid waste disposal, deals with the production, collection, and disposal of municipal waste. To date, 33 students have completed this course and 11 trainees have been supported by this grant.

PUBLICATIONS

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 01–6801, CRWR–21], [Jan. 1968], Austin, Texas.

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 08–6801], [Aug. 1968], Austin, Texas.

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 10–6801, CRWR–30], [Oct. 1968], Austin, Texas.

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 11-6801. CRWR-32]. [Nov. 1968]. Austin, Texas.

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 69-02, CRWR-35]. [Nov. 1968]. Austin, Texas.

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 68-13]. [Apr. 1969]. Austin, Texas.

Environmental Health Engineering Research Laboratory. Unpublished data. [EHE 70-01]. [Jan. 1970]. Austin, Texas.

Dr. Ross McKinney
Department of Civil Engineering
University of Kansas
Lawrence, Kansas 66045

Grant No. EC 00011-03
Funds Awarded: $116,705
Project Period: July 1, 1967 to June 30, 1972

PROGRAM: This training program provides graduate engineers at the M.S. level with a background in solid waste management for employment in State health departments, county sanitation districts, municipalities, consulting engineering firms, and Federal agencies. Graduate engineers at the Ph.D. level are trained to conduct research in solid waste management and to teach. Graduate trainees come from the various engineering departments and from the science departments. Each trainee is expected to complete a research thesis related to some aspect of solid waste management.

Presently one solid waste management course, entitled Solid Waste Disposal, is offered. This course covers most aspects of solid waste management, including characteristics of solid wastes, storage, collection, sanitary landfilling, incineration, composting, salvage and reclamation, and organizational structure of various local, State, and Federal agencies involved in solid waste management. Special problems courses are also offered wherein students are encouraged to make special investigations into a particular solid waste-related problem. The special problems permit the student to expand his knowledge in specific areas of interest.

During the past 3 academic years the solid waste disposal course has been offered once each year. Thirteen students have completed this course and 9 are about to complete it. During these 3 years, six students have taken the special problems course and conducted individual research in countywide collection and disposal, routing of collection vehicles, and chemical analysis of refuse. To date three trainees have been supported by this grant, one at the master's level and two at the Ph.D level.

This program has assisted in the establishment of a cooperative arrangement with the city of Lawrence. Currently, a Ph. D. student is supported one-half time by the city as a special assistant for solid wastes in the department of public works.

PUBLICATIONS

TILSWORTH, T. Garbage, ten million pounds a day and growing. *In* Proceedings; Governor's Conference on Environmental Problems, Topeka, Dec. 11, 1969. Kansas State Department of Health, 1970. p. 39-47.

Dr. H. Nugent Myrick
Cullen College of Engineering
University of Houston
Houston, Texas 77004

Grant No. EC 00012-02
Funds Awarded: $103,959
Project Period: July 1, 1968 to June 30, 1971

PROGRAM: This grant ensures the development of a high-quality educational and research program in the monitoring, collection, and conversion of solid wastes in the urban environment. The breadth of the program includes training and research for biologists, chemists, and all types of engineers; however, particular concern is given to ensure the continued in-depth study in the trainees' initial or desired basic scientific or engineering study discipline. Research undertaken by the trainees is related to the solution of problems of highly industrialized urban environments.

Trainees supported by this grant are required to complete a thesis related to some aspect of solid waste management and to complete the solid waste courses offered by the University of Houston. The titles of the solid waste courses to be offered and a summary of course content follows: Solid Wastes and Measurements, lecture and laboratory experiments related to the monitoring and measurement of solid wastes and their residues in the environment and on the conversion of solid wastes by conventional and advanced technology; Solid Wastes Conversion Processes, lectures on the theory of conversion process units, process design, economic analysis of processes, and model assimilation of solid waste conversion systems; Solid Waste Collection System Analysis, lectures on conventional practice and advanced technology of solid waste collection, including model assimilation of the generation and collection of solid wastes; Environmental Sciences and Engineering Seminar, seminars on the various pertinent topics or the technology, management, and science of air, water, and terrestrial pollution of urban environments.

Through the academic year of 1968–1969, only the Solid Waste Conversion and Processing course was offered. The total enrollment in this course was nine students, including seven part-time students from industry and consulting offices. To date, two students have been supported by traineeships from this grant. Both are expected to graduate with an M.S. degree in 1970.

Dr. Richard S. Engelbrecht
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801

Grant No. EC 00032–02
Funds Awarded: $85,458
Project Period: July 1, 1968 to June 30, 1973

PROGRAM: This training program provides graduate students the opportunity of becoming knowledgeable about solid waste problems and solutions so that they may be prepared to make a contribution to the field of solid waste management. This training program embraces an interdepartmental approach involving sanitary engineering, food science, and agricultural engineering. The program is limited to the M.S. level, and trainees receive a degree in one of the participating departments. All candidates for work in this area are expected to fulfill requirements in their own discipline, but as an integrating force, these same aspirants will be expected to complete the following three common courses: (1) Sources and Characteristics of Solid Waste, (2) Solid Waste Management and (3) Environmental Health Engineering, and to show necessary orientation in the area by virtue of submitting an approved thesis or independent study related to a solid waste problem. A special and separate seminar will be developed that will serve also to knit the program together. Outside speakers whose work relates directly to this area will further stimulate interest and challenge the progress of the student.

An interdepartmental approach to this problem was used because of the close relationship of the respective departments to the solid waste problem. The participation of the Department of Agricultural Engineering in this approach is desirable owing to the tremendous solid waste problems created by the agricultural community and their desire to solve these problems.

The food processing industry, from canning to the frozen food operations, produces many wastes of various types that need to be properly managed. Therefore the participation of the department of food science is important in the success of this training program. The participation of the Department of Civil Engineering in this program is needed to provide an integrated approach in enhancing municipal, agricultural, commercial, and industrial waste management.

The two solid waste courses have had an average enrollment of eight students each. So far, four students have been supported by this grant, two working toward their M.S. in sanitary engineering, one toward an M.S. in agricultural engineering, and one toward an M.S. in food science.

Dr. Frederick G. Pohland
School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Grant No. EC 00033–04
Funds Awarded: $139,679
Project Period: July 1, 1966 to June 30, 1974

PROGRAM: This program provides specialized interdisciplinary training in solid waste technology founded upon the basic and applied sciences associated with present and proposed methods of solid waste collection, transportation, and treatment. The training includes emphasis on pertinent unit processes and operations, system analysis and optimization, economic analysis and financing, and program administration. This emphasis is accentuated by a core curriculum in solid waste technology, by suggested graduate curricula in each contributing discipline, and by the use of seminars and special workshops. Solid waste trainees come from various schools, including those of civil engineering, industrial engineering, social sciences, and city planning, and will receive degrees from their respective schools.

Three solid waste courses are offered at Georgia Institute of Technology, Solid Waste Technology I and II plus a Special Problems course. Solid Waste Technology I is an introduction to the fundamentals of solid waste characterization, handling and disposal systems, physical and chemical methods of solid waste analysis, treatment methods, management and design principles, environmental impact, and control procedures. This course has been offered three times with a total enrollment of 21 students. Solid Waste Technology II is related to the evolution of typical solid waste problems, the application of design and management principles, case studies of operational solid waste systems, and the study of new methods and advanced topics. This course has also been offered three times and has had a total enrollment of 19 students. In addition to formal classes, students are exposed to solid waste management practices by special seminars with guest speakers. About 20 different guest speakers have addressed seminars to date.

During the four years of this grant, eleven students have been supported by traineeships. Of the six students that have graduated, five are now employed by governmental agencies and one by private industry.

Dr. Nathan C. Burbank Jr.
Department of Environmental Health
University of Hawaii
Honolulu, Hawaii 96822

Grant No. 00038–01
Funds Awarded: $49,223
Project Period: July 1, 1969 to June 30, 1972

PROGRAM: This grant provides the means for the introduction of three major new courses related to solid waste management for students of environmental sanitation into the curriculum of the Department of Environmental Health of the School of Public Health. The course provides comprehensive instruction in the technical, economic, and geographic factors of importance to the design and management of solid waste systems. Student trainees have the option of working toward a master of public health or a master of science degree. Trainees who wish to obtain an M.S. degree must do a thesis related to a solid waste management problem. Those working toward an M.P.H. degree are not required to submit a thesis but will be required to obtain field experience in solid wastes, e.g., work with personnel of the State health department. Further, they will be required to organize, prepare, and submit documents describing and commenting on their field experience.

The new courses in solid waste management and a brief description of each follows: Solid Waste Management and Control, covers the necessity of proper solid waste management from a public health standpoint as well as an introduction of waste generation, storage, collection, utilization, and disposal of solid waste. The Sampling and Analysis of Solid Wastes course introduces the student to physical and chemical methods of solid waste analysis. The course Design of Solid Waste Disposal Facilities incorporates the solution of problems associated with incineration, sanitary landfilling, composting, reclamation, and the various aspects of refuse collection and transportation.

PUBLICATIONS

BURBANK, N. C., JR. The importance of sanitation as applied to the tourist industry in Hawaii. *Professional Sanitation Management*, 1(4):55–59, Jan. 1970.

MCCAULEY, R. F., N. C. BURBANK, JR., and R. H. F. YOUNG. Production of charcoal from bagasse. Presented at National Industrial Solid Waste Management Conference, University of Houston, Mar. 24–26, 1970.

SECTION IV

RESEARCH AND TRAINING GRANT PRINCIPAL INVESTIGATORS

RESEARCH AND TRAINING GRANT
PRINCIPAL INVESTIGATORS

Principal Investigator	*Page*
Allan, G. Graham	102
Anderson, John R.	52
Andrews, John F.	93
Axtell, Richard C.	51
Bailie, Richard C.	81
Berry, Edward C.	27
Besley, Harry E.	27
Block, Seymour S.	71
Bloodgood, Don E.	58
Boettner, Edward A.	45
Bond, Richard G.	36, 39
Bryant, Marvin C.	74
Bugher, Robert D.	13
Burbank, Nathan C.	129
Burchinal, Jerry C.	40, 105, 106
Callihan, Clayton D.	90
Charnes, Abraham	56
Cogswell, Howard L.	102
Currier, Raymond A.	96
Dale, Alvin C.	19
Darley, Ellis F.	84
Day, Donald L.	25
Diesch, Stanley L.	35
Ecke, Dean H.	50
Engelbrecht, Richard S.	128
First, Melvin W.	43
Fontenot, Joseph P.	99
Freed, Virgil H.	76
Fungarcli, A. Alexander	109
Galler, William S.	6
Glysson, Eugene A.	124
Golueke, Clarence G.	60
Gray, Donald H.	82
Grethlein, Hans E.	82
Gross, M. Grant	113
Grove, Cornelius S.	92
Hart, Samuel A.	15, 29
Hazen, Thamon E.	23
Heimburg, Richard W.	49
Hill, Charles H.	87
Hoffman, Donald A.	69
Hortenstine, Charles C.	8
Howes, James R.	31
Hulbert, Samuel F.	17
Jeris, John S.	8
Kaiser, Elmer R.	42, 46, 68
Kelly, James L.	87
Klein, Donald A.	83
Knuth, David T.	5
Kramer, Amihud	95
Krusé, Cornelius W.	57
Leatherwood, James M.	100
Liebman, Jon C.	55
Lindsay, Willard L.	12
Long, Sterling K.	70
McKinney, Ross E.	15, 127
Malina, Joseph F., Jr.	126
Malisch, Ward R.	94
Mercer, Walter A.	3
Merz, Robert C.	107
Miller, Byron F.	73
Miller, Paul D.	48
Miner, J. Ronald	30
Morgan, Peter E. D.	77
Moulton, Lyle K.	111
Myrick, H. Nugent	16, 127
Oswald, William J.	85
Pfeffer, John T.	88
Pohland, Frederick G.	129
Purdom, P. Walton	41, 123
Rose, Walter A.	11
Sarofim, Adel F.	47
Scarsbrook, Clarence E.	4
Sheaffer, John R.	63
Shuster, William W.	72, 123
Silverman, Leslie	38
Snyder, William C.	66
Spradlin, Bobby C.	54

Preceding page blank

Stephens, Edgar R. 24
Stephenson, Marvin E. 112
Stewart, George F. 14
Susag, Russell H. 65, 124
Taiganides, E. Paul 16, 21
Thygeson, John R. 34
Updegraff, David M. 78
Wilson, David G. 89
Witzel, Stanley A. 18
Wren, Eddie J. 72, 111
Zaltzman, Raul 125
Zandi, Iraj 114

☆ U.S. GOVERNMENT PRINTING OFFICE: 1971 O—413-240

ADDENDUM*

TO

"SUMMARIES OF SOLID WASTE RESEARCH AND TRAINING GRANTS-1970" - SW-5r.2

RESEARCH GRANTS ONLY
THROUGH JULY 31, 1971

STABILIZING SANITARY LANDFILLS BY INJECTION GROUTING

Dr. Lyle K. Moulton
Department of Civil Engineering
West Virginia University
Morgantown, West Virginia 26506

EP 00016-02
Support to date: $80,550
Terminates: January 1973

DESIGN OF A WATER DISPOSABLE PACKAGING CONTAINER

Dr. Samuel F. Hulbert
Division of Interdisciplinary Studies
Clemson University
Clemson, South Carolina 29631

EP 00033-04
Support to date: $219,982
Terminates: February 1972

UTILIZATION OF BROILER LITTER AS ANIMAL FEED

Dr. Joseph P. Fontenot
Department of Animal Science
Virginia Polytechnic Institute
Blacksburg, Virginia 24601

EP 00034-03
Support to date: $102,247
Terminated: May 31, 1971

THE TREATABILITY OF LEACHATE FROM SANITARY LANDFILLS

Dr. Robert K. Ham
Department of Civil Engineering
University of Wisconsin
Madison, Wisconsin 53706

EP 00041-02
Support to date: $32,707
Terminates: May 1972

POLLUTION OF SUBSURFACE WATER BY SANITARY LANDFILL

Dr. Alex A. Fungaroli
Department of Civil Engineering
Drexel University
Philadelphia, Pennsylvania 19104

EP 00162-05
Support to date: $455,648
Terminates: August 31, 1972

CHEMICAL TRANSFORMATION OF SOLID WASTES

Dr. Virgil H. Freed
Department of Agricultural Chemistry
Oregon State University
Corvallis, Oregon 97331

EP 00242-05
Support to date: $176,695
Terminates: September 30, 1971

*Budget and administrative changes that have developed since printing of the full text are reflected in this Addendum. Prefix "EC" automatically changed to "EP" on all solid waste research grants active as of June 28, 1971.

EFFECTS OF GARBAGE COMPOST ON SOIL PROCESSES

Dr. Charles C. Hortenstine
Department of Soils
University of Florida
Gainesville, Florida 32601

EP 00250-05
Support to date: $89,423
Terminates: November 30, 1971

STUDIES OF MODIFICATIONS OF SOLID INDUSTRIAL WASTES

Dr. Cornelius S. Grove
Department of Engineering
Syracuse University
Syracuse, New York 13210

EP 00257-03
Support to date: $157,518
Terminates: June 1971

COMPREHENSIVE STUDIES OF SOLID WASTE MANAGEMENT

Dr. Clarence G. Golueke
University of California
Richmond Field Station
Richmond, California 94720

EP 00260-05
Support to date: $938,273
Terminates: May 31, 1972

STUDY OF INSTITUTIONAL SOLID WASTES

Professor Jerry C. Burchinal
Department of Civil Engineering
West Virginia University
Morgantown, West Virginia 26506

EP 00265-02
Support to date: $120,037
Terminated: June 30, 1971

ANIMAL WASTE COMPOSTING WITH CARBONACEOUS MATERIAL

Dr. William S. Galler
Department of Soil Science
North Carolina State University
Raleigh, North Carolina 27607

EP 00270-03&S1
Support to date: $67,437
Terminates: November 1971

WASTE COMPOSTS AS CHELATING AGENTS IN PLANT NUTRITION

Dr. Willard L. Lindsay
Department of Agronomy
Colorado State University
Fort Collins, Colorado 80521

EP 00273-03&S1
Support to date: $59,740
Terminates: September 1971

UTILIZATION OF FIBROUS WASTES AS SOURCES OF NUTRIENTS

Dr. James M. Leatherwood
Department of Animal Science
North Carolina State University
Raleigh, North Carolina 27607

EP 00274-04
Support to date: $108,526
Terminates: January 1972

UTILIZATION OF BARK WASTE

Professor Raymond A. Currier
Forest Research Laboratory
Oregon State University
Corvallis, Oregon 97331

EP 00276-04
Support to date: $212,478
Terminated: May 1971

SOLID WASTE DISPOSAL AND BIRD HAZARD TO AIRCRAFT

Dr. Howard L. Cogswell
Department of Biological Science
California State College
Hayward, California 94542

EP 00277-03
Support to date: $63,123
Terminates: November 1971

LASER MEDIATED LIGNIN SOLID WASTE FERMENTATION

Dr. Donald A. Klein
Department of Microbiology
Oregon State University
Corvallis, Oregon 97331

EP 00278-03
Support to date: $48,303
Terminates: May 30, 1972

DECISION MAKING AND SOLID WASTE DISPOSAL

Dr. John R. Sheaffer
Center for Urban Studies
University of Chicago
Chicago, Illinois 60637

EP 00281-02
Support to date: $201,008
Terminated: April 1971

A RECIRCULATING WASTE SYSTEM FOR SWINE UNITS

Dr. Ronald J. Miner
Department of Agricultural Engineering
Iowa State University
Ames, Iowa 50010

EP 00283-03
Support to date: $58,153
Terminates: November 1971

THERMOPHILIC METABOLISM IN SOLID SUBSTRATES

Dr. Marvin E. Stephenson
Department of Civil Engineering
Michigan State University
East Lansing, Michigan 48823

EP 00292-03
Support to date: $105,625
Terminated: May 31, 1971

SURVIVAL OF PATHOGENS IN ANIMAL MANURE DISPOSAL

Dr. Stanley L. Diesch
Dept. of Veterinary Microbiology
and Public Health
University of Minnesota
Minneapolis, Minnesota 55455

EP 00302-03
Support to date: $116,208
Terminates: May 1972

INCINERATION OF PLASTICS FOUND IN MUNICIPAL REFUSE

Dr. Richard W. Heimburg
Department of Mechanical Engineering
Syracuse University
Syracuse, New York 13210

EP 00304-03&S1
Support to date: $313,487
Terminates: February 1972

ENGINEERING PROPERTIES OF COMPACTED ASH FILLS

Dr. Donald H. Gray
Dept. of Civil Engineering
University of Michigan
Ann Arbor, Michigan 48104

EP 00317-02
Support to date: $40,455
Terminated: April 1971

WOOD WASTE REUSE IN CONTROLLED RELEASE PESTICIDES

Dr. G. Graham Allan
Institute of Forest Products
University of Washington
Seattle, Washington 98105

EP 00319-03&02S1
Support to date: $116,644
Terminates: May 1972

FIRESIDE METAL WASTAGE IN MUNICIPAL INCINERATORS

Dr. Paul D. Miller
Department of Chemistry and Biology
Battelle Memorial Institute
Columbus, Ohio 43201

EP 00325-03&S1
Support to date: $342,964
Terminates: February 1972

CONVERTING INCINERATOR RESIDUE TO USEFUL MATERIALS

Dr. Peter E. D. Morgan
Franklin Institute Research Labs.
20th and Benjamin Franklin Parkway
Philadelphia, Pennsylvania 19103

EP 00326-02
Support to date: $99,957
Terminated: April 30, 1971

SINGLE CELL PROTEINS FROM CELLULOSIC WASTES

Dr. Charles R. Dunlap
Department of Chemical Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

EP 00328-03
Support to date: $286,854
Terminates: February 1973

USE OF DOMESTIC WASTE GLASS FOR URBAN PAVING

Dr. Ward R. Malisch
Department of Civil Engineering
University of Missouri
Columbia, Missouri 65401

EP 00329-03
Support to date: $101,405
Terminates: May 1972

CRITERIA FOR DESIGN AND CONTROL OF INCINERATORS

Dr. Adel F. Sarofim
Department of Chemical Engineering
Massachusetts Inst. of Technology
Cambridge, Massachusetts 02139

EP 00330-03
Support to date: $193,192
Terminates: May 1972

NATIONAL INDUSTRIAL SOLID WASTE MANAGEMENT CONFERENCE

Dr. H. Nugent Myrick
Department of Environmental Science and Engineering
University of Houston
Houston, Texas 77004

EP 00331-01
Support to date: $29,500
Terminated: April 30, 1971

STANDARD TEST PROCEDURES FOR MUNICIPAL SOLID WASTES

Dr. Russell H. Susag
University of Florida
Gainesville, Florida 32601

EC 00332-01
Support to date: $38,887
Terminated: May 31, 1971

REFUSE RECLAMATION BY SIZE REDUCTION AND SEPARATION

Dr. David G. Wilson
Department of Mechanical Engineering
Massachusetts Inst. of Technology
Cambridge, Massachusetts 02139

EP 00333-03
Support to date: $218,748
Terminated: June 1973

RECLAMATION OF ENERGY FROM ORGANIC REFUSE

Dr. John T. Pfeffer
Department of Civil Engineering
University of Illinois
Urbana, Illinois 61801

EP 00364-02
Support to date: $75,850
Terminates: July 1972

CHEMICAL CONVERSION OF WOOD AND CELLULOSIC WASTES

Dr. Fred Shafizadeh
Department of Chemistry
University of Montana
Missoula, Montana 59801

EP 00370-01
Support to date: $36,458
Terminates: February 1974

COMBUSTION PRODUCTS FROM THE INCINERATION OF PLASTICS

Dr. Edward A. Boettner
Department of Industrial Health
University of Michigan
Ann Arbor, Michigan 48104

EP 00386-02
Support to date: $82,711
Terminates: July 1972

MARINE DISPOSAL OF FINE-GRAINED WASTE SOLIDS

Dr. M. Grant Gross
Marine Sciences Research Center
State University of New York
Stony Brook, New York 11790

EP 00388-02
Support to date: $176,151
Terminates: January 1972

RESEARCH ON AN ANIMAL WASTE POLLUTION CONTROL SYSTEM

Dr. Elihu D. Grossman	EP 00390-02
Dept. of Chemical Engineering	Support to date: $91,373
Drexel Institute of Technology	Terminates: July 1972
Philadelphia, Pennsylvania 19104	

PREVENTING LANDFILL LEACHATE CONTAMINATION OF WATERS

Mr. Eddie J. Wren	EP 00393-02
Dept. of Environmental Science	Support to date: $95,790
Plantation Park Laboratories	Terminates: January 1972
Baton Route, Louisiana 70808	

HIGH ENERGY GAS FROM REFUSE USING FLUIDIZED BEDS

Dr. Richard C. Bailie	EP 00399-03
Dept. of Chemical Engineering	Support to date: $293,556
West Virginia University	Terminates: June 1972
Morgantown, West Virginia 26506	

REUSE OF PLASTICS RECOVERED FROM SOLID WASTES

Dr. Donald R. Paul	EP 00411-01
Dept. of Chemical Engineering	Support to date: $23,342
The University of Texas	Terminates: July 1973
Austin, Texas 78712	

SOLID WASTE CELLULOSE DEGRADATION BY THERMOACTINOMYCES

Dr. Fred J. Stutzenberger	EP 00420-01
Department of Microbiology	Support to date: $9,982
Weber State College	Terminated: November 1971
Ogden, Utah 84403	

STUDY OF ECONOMICS OF HOSPITAL SOLID WASTES SYSTEMS

Dr. Richard G. Bond	EP 00458-02
School of Public Health	Support to date: $94,956
University of Minnesota	Terminates: May 1972
Minneapolis, Minnesota 55455	

TIME-SETTLEMENT OF BEHAVIOR OF PROCESSED REFUSE

Dr. Arley G. Franklin	EP 00466-01
Department of Civil Engineering	Support to date: $32,886
Northwestern University	Terminates: February 1973
Evanston, Illinois 60201	

SCRAP RUBBER TIRE UTILIZATION IN ROAD DRESSINGS

Mr. Benson G. Brand
Polymer and Paper Technology Division
Battelle Memorial Institute
Columbus, Ohio 43201

EP 00500-01
Support to date: $51,018
Terminates: May 1974

NATIONAL CONFERENCE ON SOLID WASTE DISPOSAL SITES

Mr. George M. Tomsho
American Public Works Association
Chicago, Illinois 60637

EP 00502-01
Support to date: $32,355
Terminated: June 30, 1971

SOLID WASTE CONVERSION: CELLULOSE LIQUEFACTION

Dr. Alvin H. Weiss
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Worcester, Massachusetts 01609

EP 00516-01
Support to date: $75,901
Terminates: February 1973

FABRICATION OF SINGLE CELL PROTEINS FROM CELLULOSIC WASTES

Dr. William H. Daly
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EP 00524-01
Support to date: $14,888
Terminates: July 1973

ANALYSIS MODELS FOR SOLID WASTE COLLECTION

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EP 00552-01
Support to date: $38,615
Terminates: May 1973

FORMATION OF SILICON CARBIDE FROM RICE HULLS

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EP 00558-01
Support to date: $21,621
Terminates: May 1974

SIZE REDUCTION IN SOLID WASTE PROCESSING

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Division of Thermal Systems
University of California
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EP 00570-01
Support to date: $20,316
Terminates: May 1973

BUSINESS ANALYSIS OF THE SALVAGE INDUSTRY

Mr. Robert M. Sontheimer
Resource Planning Institute, Inc.
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Cambrdige, Massachusetts 02142

EP 00600-01
Support to date: $60,047
Terminates: May 1972

ROUTING OF SOLID WASTE COLLECTION VEHICLES

Dr. John C. Liebman
Department of Environmental Health
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Baltimore, Maryland 21218

EP 00602-01
Support to date: $52,928
Terminates: May 1973

SANITARY LANDFILL STABILIZATION WITH LEACHATE RECYCLE

Dr. Frederick G. Pohland
Sanitary Engineering Laboratories
School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

EP 00658-01
Support to date: $24,739
Terminates: May 1973

THE METALLURGICAL UPGRADING OF AUTOMOTIVE SCRAP STEEL

Dr. Norman O. Carlson
Ames Laboratory
c/o Iowa State University
Ames, Iowa 50010

EP 00667-01
Support to date: $39,998
Terminates: May 1973

AN INFRA-RED SPECTRAL SENSOR FOR REFUSE SORTING

Dr. Frank P. Winkler
Department of Physics
Middlebury College
Middlebury, Vermont 05753

EP 00682-01
Support to date: $20,735
Terminates: May 1973

AN EXPERIMENTAL HIGH ASH PAPERMILL SLUDGE LANDFILL

Dr. Orlando B. Andersland
Division of Engineering Research
Michigan State University
East Lansing, Michigan 48823

EP 00685-01
Support to date: $89,616
Terminates: May 1973

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